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September 1999

Environmental Technology Verification Report

France Compressor Products Emissions Packing

Phase I Report

Prepared by:

Southern Research Institute

Under a Cooperative Agreement with
U.S. Environmental Protection Agency

EPA REVIEW NOTICE

SRI/USEPA-GHG-VR-03
September 1999

Greenhouse Gas Technology Verification Center

A U.S. EPA Sponsored Environmental Technology Verification Organization

France Compressor Products
Emissions Packing

Phase I
Technology Verification Report

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Under Cooperative Agreement CR 826311-01-0

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TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The U. S. Environmental Protection Agency's (EPA) Office of Research and Development has created the Environmental Technology Verification (ETV) Program to facilitate the deployment of promising environmental technologies. Under this program, third-party performance testing of environmental technology is conducted by independent Verification Organizations. Their goal is to objectively and systematically evaluate technology performance under strict EPA quality assurance guidelines. The EPA's Air Pollution Prevention and Control Division has selected Southern Research Institute as the independent Verification Organization to operate the Greenhouse Gas Technology Verification Center (the Center). With full participation of technology providers and users, the Center develops testing plans and conducts field and laboratory tests. The test results undergo analysis and peer review, and are then distributed to industry, regulatory agencies, vendors, and other interested groups.

The Center has completed the verification testing of the Emissions Packing technology. This technology is offered by France Compressor Products, and is designed to reduce methane leaks from compressor rod packing when a compressor is in a standby and pressurized state. Performance testing was carried out at a compressor station operated by ANR Pipeline Company of Detroit, Michigan. The test was carried out on two separate engines, each with two compressor units. The Emissions Packing was installed on a single Test Rod of the two engines (Engines 501 and 502). The remaining rod on each engine contained standard packing, serving as a Control Rod against which Emissions Packing performance could be compared. The Control Rod packing was outfitted with new seals at the same time the Emissions Packing was installed, facilitating a more direct comparison of the Test and Control Rods. The evaluation focused on two shutdown procedures that represent the most common approaches to compressor shutdown: remain pressurized during idle; and depressurized (blow down) before idle. The goals of the test were to: verify initial gas savings for primary baseline conditions, and document initial costs and installation requirements.

This document reports the results of the Phase I test which consisted of short-term performance evaluation and documentation of initial costs. The Phase I test was executed between July 16 and July 30, 1999. The following performance results were verified:

- The Emissions Packing did not reduce compressor rod packing leaks during standby idle mode. The average difference (both engines) between the Control Rod and Test Rod was -0.29 $\pm$ 0.55 scfm natural gas. For Engine 501, the Test Rod emitted more gas than the Control Rod (-0.54 $\pm$ 0.47 scfm natural gas). For Engine 502, no significant increase in emissions (-0.04 $\pm$ 0.55 scfm) was detected.

- Of the 14 samples collected over a 7-day test period, the emission differences between the Control Rod and the Test Rod were observed to range between -1.35 and +0.55 scfm. Ten measurements showed a loss in gas savings, and four samples showed a gas savings. It is believed that these savings are due to the differences in rod material, not the improvements caused by the Emissions Packing (the Test Rod was ceramic coated while the Control Rod was alloy steel).

- The Emissions Packing uses spring-loaded pressure plates, along with conventional sealing rings, to provide static sealing capability during idle periods. To make room for these pressure plates, a seal had to be removed from the Test Rod, which is not the case with conventional packing. To determine if the missing seal alters the emission sealing performance of the overall packing system, measurements were collected on the Test and Control Rods while the engines were running. Based on 14 samples collected at the doghouse vents, the Emissions Packing was found to slightly increase rod packing leaks by -0.05 $\pm$ 0.38 scfm (Control Rod emissions minus Test Rod emissions ranged from -0.59 to +0.52 scfm).

- While the engines were pressurized, fugitive leaks at the blowdown valve were measured to be 0.08 scfm. No leaks were found from the pressure relief valve and other miscellaneous equipment (e.g., valves and fittings). The average unit valve leak rate (combined for both compressors) was 12.14 scfm.

- For a baseline operating scenario identified with a compressor that normally remains pressurized during idle periods, the net gas savings for both test engines were determined to be -18,224 ± 29,987 scf natural gas. This is based on the compressor operating schedule encountered at the test site (idle periods equal 908 hours or 53 percent of the total available operating time).

- For a baseline operating scenario identified with a compressor that normally blows down to atmospheric pressure, the net gas savings for both test engines were determined to be 651,261 ± 47,775 scf natural gas. The gas savings achieved here are attributable to the change in operating practice (i.e., elimination of blowdown volume and unit valve leaks), not the Emissions Packing.

- Installation of the Emissions Packing was completed in 27 labor hours (per rod), which is the same amount of time required to install conventional packing. On a per rod basis, the capital cost for the Emissions Packing was $3,426.42. The cost for the conventional packing is about $3,500.00, which is the same as for the Emissions Packing. Consequently, no incremental cost increases were observed with the Emissions Packing.

ACKNOWLEDGMENTS

The Greenhouse Gas Technology Verification Center wishes to thank the staff and employees of ANR Pipeline Company for their invaluable service in hosting this test. They provided the compressor station to test this technology, and gave technical support during the installation and shakedown of the technology. Key individuals who should be recognized include Curtis Pedersen, Dwight Chutz, and Earl Prince. Thanks are also extended to the Center's Oil and Natural Gas Industry Stakeholder Group for reviewing this report.

1.0 INTRODUCTION

1.1 BACKGROUND

The U.S. Environmental Protection Agency's Office of Research and Development (EPA-ORD) has created a program to facilitate the deployment of innovative technologies through performance verification and information dissemination. The goal of the Environmental Technology Verification (ETV) program is to further environmental protection by substantially accelerating the acceptance and use of improved and more cost-effective technologies. The ETV program is funded by the Congress in response to the belief that there are many viable environmental technologies which are not being used because of the lack of credible third-party performance testing. With performance data developed under this program, technology buyers, financiers, and permitters in the United States and abroad will be better equipped to make informed decisions regarding environmental technology acquisitions.

The Greenhouse Gas (GHG) Technology Verification Center (the Center) is one of 12 independent verification entities operating under the ETV program. The Center is managed by EPA's partner verification organization, Southern Research Institute (SRI), and conducts verification testing of promising GHG mitigation and monitoring technologies. This Center's verification process consists of developing verification protocols, conducting field tests, collecting and interpreting field and other data, and reporting findings. Performance evaluations are conducted according to externally reviewed Verification Test Plans and established protocols for quality assurance.

The Center is guided by volunteer groups of Stakeholders. These Stakeholders offer advice on technology areas and specific technologies most appropriate for testing, help disseminate results, and review test plans and verification reports. The Center's Executive Stakeholder group consists of national and international experts in the areas of climate science, and environmental policy, technology, and regulation. It also includes industry trade organizations, environmental technology finance groups, various governmental organizations, and other interested groups. The Executive Stakeholder Group helps identify and select technology areas for verification. For example, the oil and gas industry was one of the first areas recommended by the Executive Stakeholder Group as having a need for high quality performance verification.

To pursue verification testing in the oil and gas industries, the Center established an Oil and Gas Industry Stakeholder Group. The group consists of representatives from the production, transmission, and storage sectors. It also includes technology vendors, technology service providers, environmental regulatory groups, and other government and non-government organizations. This group has voiced support for the Center's mission, identified a need for independent third-party verification, prioritized specific technologies for testing, and identified broadly acceptable verification strategies. They also indicated that technologies that reduce methane leaks from compressor rod packings are of great interest to the technology purchasers. In the natural gas industry, interstate gas pipeline operators use large gas-fired engines to provide the mechanical energy needed to drive pipeline gas compressors. In the U.S., fugitive natural gas leaks from these compressors represent a major source of methane emissions, and a loss of economic and natural resources.

To pursue verification testing on compressor rod packing technologies, the Center placed formal announcements in the Commerce Business Daily and industry trade journals to invite vendors of commercial products to participate in independent testing. France Compressor Products (parent company: Coltec Industries, Inc.) responded, committing to participate in a medium-term independent verification of their new rod packing technology. The technology is referred to as the Emissions Packing, and is designed to reduce methane leaks from compressor rod packing during periods when the compressor is in a standby and pressurized state.

Performance testing of the Emissions Packing was carried out at a compressor station operated by ANR Pipeline Company (ANR) of Detroit, Michigan. The verification test was originally planned to be executed in two phases where: Phase I verified short-term gas savings and documented installation costs; and Phase II addressed longer-term technical and economic performance. This report presents the results of the Phase I test, which occurred between June 16 and July 30, 1999.

Details on Phase I and II verification test design, measurement test procedures, and Quality Assurance/Quality Control (QA/QC) procedures can be found in the report: *Testing and Quality Assurance Plan for the France Compressor Products Emissions Packing* (SRI 1999). It can be downloaded from the Center's Web site at www.sri-rtp.com. The Test Plan describes the rationale for the experimental design, the testing and instrument calibration procedures planned for use, and specific QA/QC goals and procedures. The plan was reviewed and revised based on comments from France Compressor Products, ANR Pipeline, selected members of the Oil and Gas Industry Stakeholder Group, and the EPA Quality Assurance Team. The plan meets the requirements of the Center's Quality Management Plan (QMP), and conforms with EPA's quality standard for environmental testing (ANSI/ASQC E-4 1994). In some cases, deviations from the Test Plan were required. These deviations, and the alternative procedures selected for use, are discussed in this report.

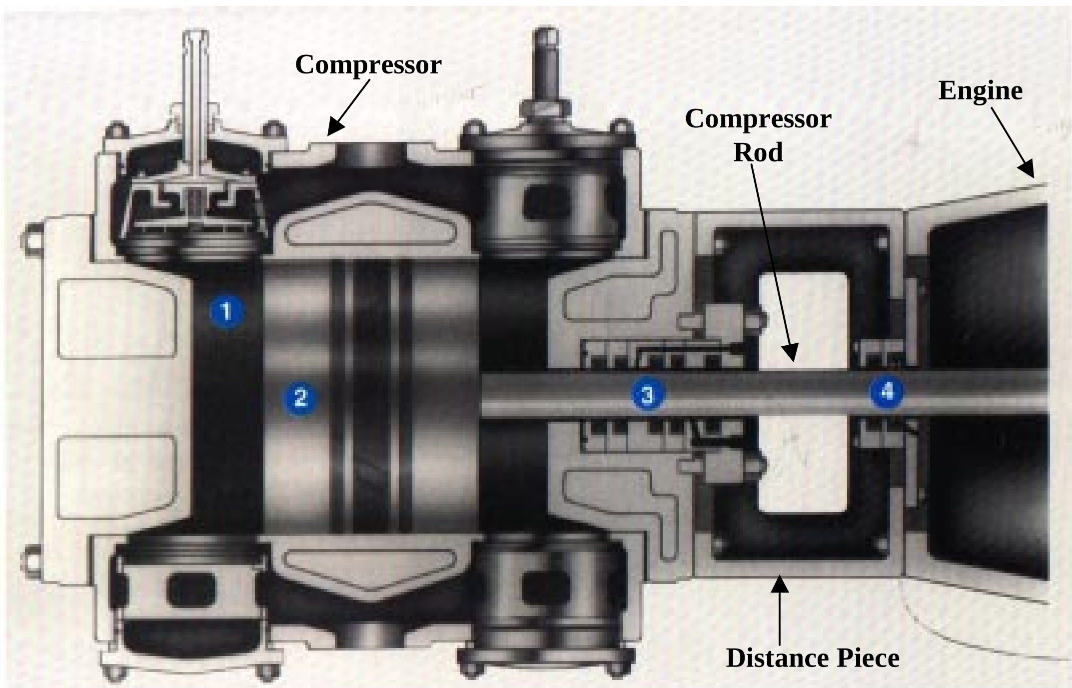
This section also provides a description of the Emissions Packing technology and the goals of the verification tests. Section 2 presents a background discussion of methane emissions from natural gas compressors and descriptions of the test site, and the measurement system employed at the test site. Section 3 presents Phase I test results, and Section 4 assesses the quality of the data.

1.2 THE EMISSIONS PACKING TECHNOLOGY

One of the largest sources of fugitive natural gas emissions from compressor operations is the leakage associated with operating and idle-mode compressor rod packing. During standby conditions, natural gas leaks into the atmosphere from the packing case and other compressor emission sources. Based on an EPA/GRI study, reciprocating compressors in the gas transmission sector were operating 45 percent of the time in 1992 (Hummel et al. 1996). If rod leaks during standby operations are reduced or eliminated, significant gas savings and emissions reductions could be realized. France Compressor Emissions Packing is intended to provide this benefit.

In general, compressor packing provides a seal around the rod shaft, keeping high pressure gas contained in the compressor from leaking out into the atmosphere. A typical compressor packing case is shown in Figure 1-1 (see location No. 3). It consists of one or more sealing rings contained within a case that serves several functions. These functions include: lubrication, venting, purging, cooling, temperature and pressure measurement, leakage measurement, rod position detection, and sealing for standby mode operations (GRI 1997). In conventional packing, the sealing rings are configured in series to successively restrict the flow of gas into the distance piece between the compressor and the engine. The sealing rings are held in separate grooves or “cups” within the packing case, and are free to move laterally along with the rod, and free to “float” within the grooves. The distance piece, shown between locations 3 and 4 in Figure 1-1, typically vents rod packing leaks to the atmosphere.

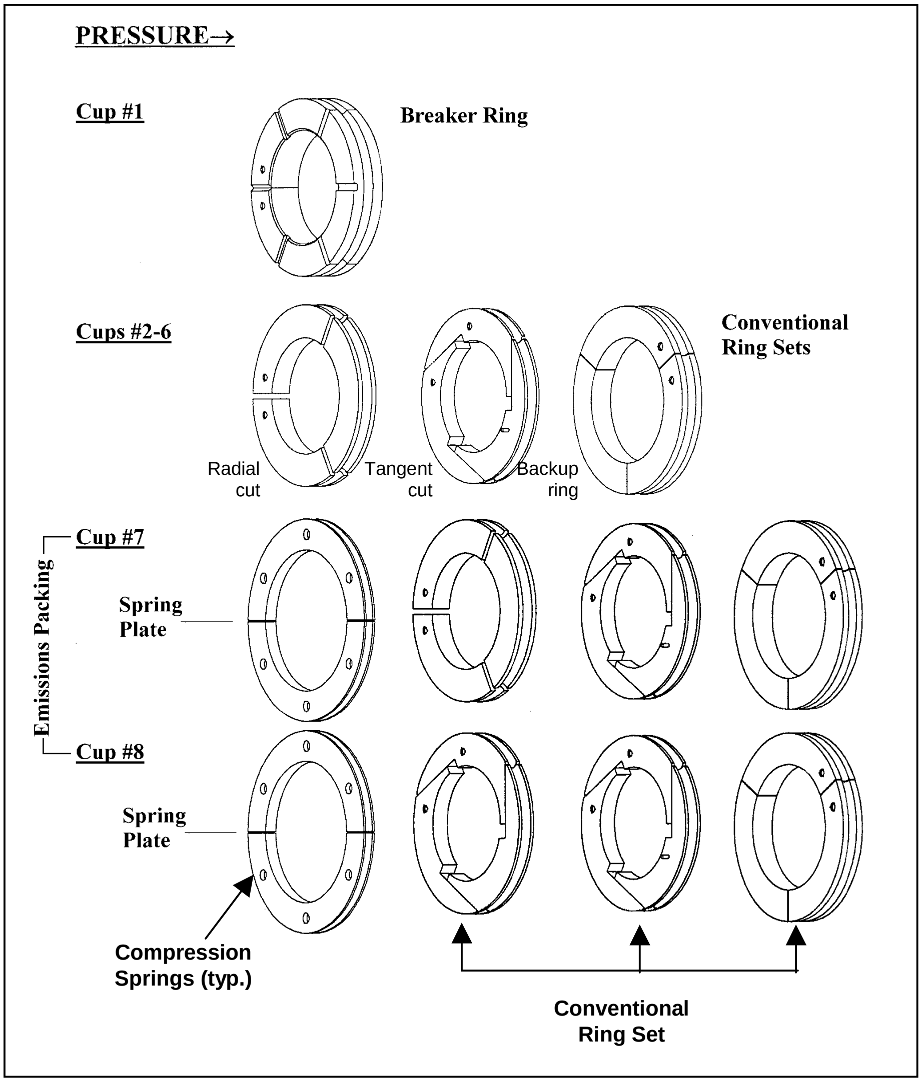
Figure 1-1. Schematic of a Gas Compressor Engine and Rod Packing



1 Compressor Valves and Unloaders
2 Piston & Rider Rings
3 Packing Rings & Case
4 Oil Wiper Rings & Cases

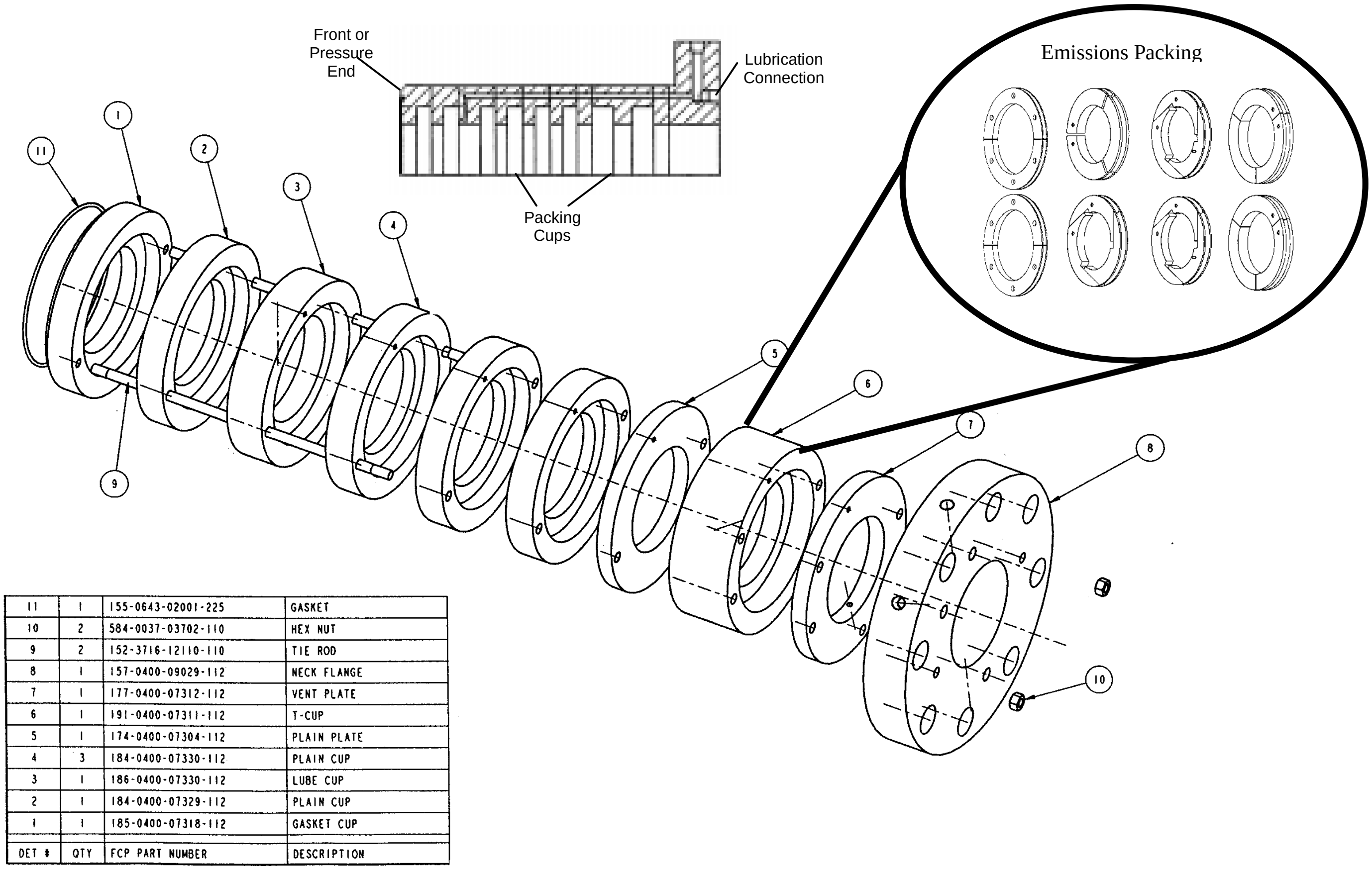
A conventional packing case typically contains seven to nine cups. Each cup houses one or more seal rings, which restrict the flow of natural gas to atmosphere or out into the distance piece. Each ring seals against the piston rod and also against the face of the packing cup. The first cup is occupied by the breaker ring (see Figure 1-2) whose designed function is to reduce the pressure on the packing rings by providing an orifice restriction to flow. A second function of the breaker ring is to regulate the reverse flow of gas from the packing case into the cylinder. This reverse flow occurs as the piston begins the intake stroke, and the pressure is rapidly reduced in the cylinder.

Figure 1-2. France Emissions Packing - Ring Detail



Cups 2 through 6 are occupied by conventional three-ring packing sets which consist of a "radial cut" ring, a "tangent cut" ring, and a "backup" ring (see Figure 1-2). During the discharge stroke, while the compressor is operating, pressure is exerted on each ring. This forces the rings to mate against each other, and reduce leakage laterally along the rod. During this time, the tangent cut ring constricts against the rod, reducing leakage past the rod surface. During the intake stroke, pressure is rapidly reduced in the cylinder, and gas flows from around the sealing rings back toward the cylinder. During this cycle, the rings are free to move back and forth within the cups (depending on how much differential pressure is experienced between the discharge and intake strokes and the movement of the rod). The final cup houses a vent control ring which can be used to transport the leaking gas for subsequent use or discharge into the distance piece. A more detailed description of rod packing is given in GRI's report documenting existing compressor rod packing technology and emissions (GRI 1997).

Figure 1-3. France Emissions Packing



DET #	QTY	FCP PART NUMBER	DESCRIPTION
11	1	155-0643-02001-225	GASKET
10	2	584-0037-03702-110	HEX NUT
9	2	152-3716-12110-110	TIE ROD
8	1	157-0400-09029-112	NECK FLANGE
7	1	177-0400-07312-112	VENT PLATE
6	1	191-0400-07311-112	T-CUP
5	1	174-0400-07304-112	PLAIN PLATE
4	3	184-0400-07330-112	PLAIN CUP
3	1	186-0400-07330-112	LUBE CUP
2	1	184-0400-07329-112	PLAIN CUP
1	1	185-0400-07318-112	GASKET CUP

During idle periods the unit remains pressurized, and pressure equalizes around the rings and they can float within the cups. While they are floating, the pressure breaker rings and other rings downstream of the packing are not designed to stop gas leakage. As a result, rod packing leaks continue when the rod motion has stopped. The leakage encountered during idle periods is due to the loss of lubrication oil which normally fills the leak paths, changes in the shape of the ring as it cools, and changes in rod alignment as the temperature changes (GRI 1997).

France Compressor Products (France) offers the Emissions Packing system to reduce leakage during idle periods. The Emissions Packing system is shown in Figure 1-3. The Emissions Packing appears identical to a conventional rod packing, with the exception that the final two cups in a conventional packing are replaced with a single France “T-cup”. The France “T-Cup”, which is shown as item 6 in Figure 1-3, contains two spring-loaded pressure plates in addition to the six sealing rings originally contained in the conventional packing. The spring-loaded pressure plate and the remaining three conventional rings in the “T-cup” are intended to provide a positive and continuous seal during idle periods. The pressure plate is a two-piece radial cut ring with several compression springs equally spaced around the ring that exert a force parallel to the rod. While the compressor is in an idle, pressurized state, the spring-loaded pressure plate exerts a force in the direction of the conventional rings (see the direction of the arrows in Figure 1-2). As a result of this action, the adjacent seals experience a force similar to that encountered during the discharge stroke while the compressor is operating, causing the rings to mate together and constrict the tangent cut ring against the rod.

To allow room for the addition of the pressure plates, the France Packing contains one less ring set than conventional packing. France did not expect this modification to influence running or idle emissions; however, both of these factors were quantified in the verification test.

1.3 VERIFICATION GOALS

Normal compressor shutdown and standby procedures vary from station to station. Some operators depressurize and blow down all pressure from a compressor before standby. Others depressurize the compressor to a lower, but elevated, pressure, while still others maintain full pressure during standby. Adding the Emissions Packing to a compressor may result in varying levels of net gas savings and emission reductions depending on the shutdown procedure used. Evaluation of the Emissions Packing focused on two shutdown procedures that represent the most common approaches to compressor shutdown: remain pressurized during idle; and depressurize (blow down) before idle. Shutdown modes are discussed in Section 2.1.

The Phase I and II verification goals and parameters associated with the two compressor shutdown scenarios are outlined below.

Phase I Evaluation:

Verify initial gas savings for primary baseline conditions
Document installation and shakedown requirements
Document capital and installation costs

Phase II Evaluation:

Document annualized gas savings for primary baseline conditions
Verify annual methane emission reduction
Calculate and document Emissions Packing payback period

Phase I goals were achieved through observation, collection, and analyses of direct gas measurements, and the use of site logs and vendor-supplied cost and operational data. The evaluation was completed after about a 4-week period. Initial gas savings were based on three sets of manual emission measurements conducted at roughly equal intervals (beginning, middle, and end of the test period). The number and duration of shutdowns were determined from site records provided by ANR Pipeline Company for the testing period, and for prior years. Measured emission rates, site operational data, estimated gas savings, and installation requirements are documented and verified in this report.

A primary goal of the Phase II evaluation is to determine the Emissions Packing payback period. As a practical matter, the Center cannot conduct testing for the number of years that would be required to determine payback from direct measurements. Thus, several Phase II goals will be accomplished through a combination of medium-term measurements (several months) and data extrapolation techniques. A Phase II report is planned for release in 2000.

2.0 TECHNICAL BACKGROUND AND VERIFICATION APPROACH

2.1 METHANE EMISSIONS FROM NATURAL GAS COMPRESSORS

Fugitive natural gas emissions from compressor stations account for a significant loss in revenue for gas companies and increase a company's unaccounted for gas losses. These emissions also contribute to the release of methane, a potent greenhouse gas, into the atmosphere. Prior EPA and Gas Research Institute studies estimated that reciprocating compressors emitted approximately 21 percent of the total gas emissions (314 billion cubic feet) from the natural gas industry in 1992 (Harrison et al. 1996).

Methane emissions from compressors are liberated from a variety of different sources. These sources include leaks from the rod packing, unit valves, the blowdown valve, the pressure relief valve, and miscellaneous valves, fittings, and other devices. Emissions from blowdown operations are also significant. One source of fugitive natural gas emissions is the leakage associated with compressor rod packing. Most leaks occur from operating compressors, but emissions also occur when some compressors are placed into a standby or idle mode while remaining pressurized.

According to an ongoing multiyear compressor station fugitive emissions study conducted by the Pipeline Research Committee, very little difference was observed between the overall average value of running rod packing emissions and pressurized, but idle, rod emissions. The overall average leak rate was approximately 1.9 cfm per rod (GRI 1997). The study also concluded that very large differences at a single site can be encountered, and individual measurements can be highly variable within a single year, particularly among the idle pressurized compressors. These results are based on data collected from 9 compressor stations, containing 56 reciprocating compressors and readings taken at 365 individual rod packings.

Fugitive emissions from standby or idle-mode compressors are affected by the compressor shutdown mode which varies from station to station. In general, the following procedures are used:

- Maintain full operating pressure when idle (either with or without the unit isolation valves open),
- Depressurize and blow down all pressure when idle (except a small residual pressure to prevent air in-leakage) and vent the gas, either partially or completely, to the atmosphere,
- Depressurize to a lower pressure, venting the gas either to the atmosphere or to the station fuel system, or
- A combination of these procedures.

Based on an EPA/GRI study (Harrison et al. 1996), the first two operating procedures represent the most common approaches to compressor shutdown. The study estimated that about 57 percent of idle transmission compressors are maintained at operating pressures and 38 percent are blown down to the atmosphere. A smaller percentage (less than 5 percent) is blown down to a lower pressure, in some cases venting to the station's fuel system.

2.2 DESCRIPTION OF THE TEST SITE AND EMISSIONS PACKING INSTALLATION

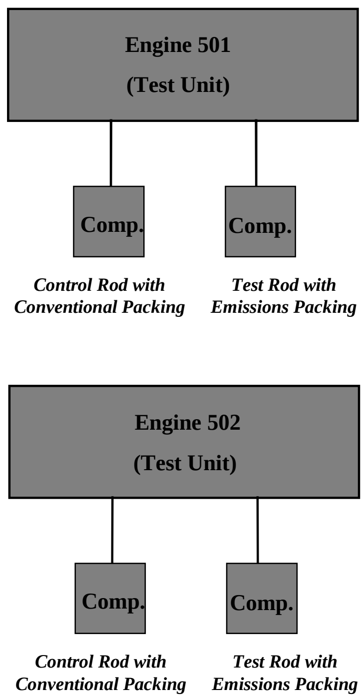
Reciprocating compressors are the type most commonly used within the gas transmission industry, and are a primary source of compressor-related emissions. Thus, the Emissions Packing verification was conducted at a transmission station that uses reciprocating compressors. ANR Pipeline Company expressed interest in hosting the verification, and assisted the Center in identifying a representative compressor station within their pipeline system. ANR reviewed its operations and identified facilities where: Emissions Packing was not currently used; at least one compressor operates in a shutdown mode several times a year; and site operators could cooperate in support of the short- and long-term evaluations.

The natural gas transmission engine/compressor selected to host the Emissions Packing evaluation operates six Cooper-Bessemer engines (8 cylinder, 2000 hp), each equipped with two reciprocating compressors operating in series (4,275 cubic inch displacement, 4-inch rods). The low-speed engines at the site are typical of many used in the industry, but may not be typical of newer, high-speed engines in use. The rods and packing cases have the same basic design and function as most reciprocating compressors currently used and planned for use in the future in the transmission sector. The rod packing is essentially a dry seal system, using only a few ounces of lubricant per day. Wet seals, which use high-pressure oil to form a barrier against escaping gas, have traditionally been employed. According to the natural gas STAR partners, dry seal systems have recently come into favor because of lower power requirements, improved compressor and pipeline operating efficiency and performance, enhanced compressor reliability, and reduced maintenance. The STAR industry partners report that about 50 percent of new seal replacements consist of dry seal systems.

Two engines, designated 501 and 502, were selected to verify the performance of the Emissions Packing system (see Figure 2-1 for a simplified floor plan). These two engines are the same age and have similar operating hours, which is ANR's normal operating practice. Actual operating hours on each engine are logged continuously. Each engine contains two compressor rods, and nine cups are contained in each packing case. The Emissions Packing was installed on a single rod on each engine by removing the final three sealing cups and replacing them with France "T-cups". All the standard packing was also replaced. This rod is referred to as the Test Rod, and it contains one less ring set than the original packing because of the addition of the pressure plates. France did not expect this modification to influence running or idle emissions; but measurements were made to verify this claim.

The remaining rod on each engine contained standard packing, and served as a Control Rod against which Emissions Packing performance was compared. The Control Rod packing was outfitted with new seals at the same time the Emissions Packing was installed, allowing a more direct comparison between the Test and Control Rods. All rods are made of alloy steel, with the exception of the Test Rod on Engine 502. The material on this rod is ceramic-coated steel, which has been used at this site to reduce oil usage in the seals.

Figure 2-1. Simplified Floor Plan of the Test Site



2.3 VERIFCATION APPROACH

2.3.1 Establishing Baseline Conditions

According to France, the Emissions Packing can provide static sealing during idle periods, provided the compressor remains pressurized. Of course, the gas savings achieved depend on the emission characteristics of the compressors packing, both before and after installation of the France Emissions Packing. Gas savings also depend on the shutdown procedures used, and the number and duration of shutdowns experienced. For example, a station that currently leaves compressors pressurized during shutdown will achieve net savings from the decrease in rod packing leaks during idle. Alternatively, if a station currently blows down compressors before shutdown, installing the Emissions Packing would be associated with a change in operating practice to a pressurized shutdown condition. A likely scenario for such a change would be that the station wishes to eliminate blowdown emissions, and employs a static sealing system at the same time to reduce or eliminate any new emissions from the newly pressurized rod packings. In this case, gas savings occur by eliminating blowdown emissions and unit valve leaks. However, there is a potential for increases in emissions from components now exposed to high pressure during shutdown.

For the two most commonly used compressor shutdown scenarios described in Section 2.1, Table 2-1 shows the relationship between compressor shutdown procedures and emissions. Since use of the Emissions Packing system is associated with a pressurized compressor standby operation, the table indicates how compressor emissions may change from the emissions that occurred during the original standby mode. Using this table as a guide, a verification plan was developed to characterize all the emissions changes that may occur with the installation of the Emissions Packing and the possible adoption of a different shutdown procedure.

The evaluation of the Emissions Packing performance at ANR Pipeline Company focused on the two shutdown scenarios that collectively represent practices employed by about 95 percent of the transmission compressors (Shires and Harrison 1996). Case 1 represents compressors that remain pressurized when idle, and Case 2 represents compressors that completely depressurize and blow down all gas. The host site was asked to follow these practices during testing, although their normal practice is to maintain idle pressures of about 120 psig and recover all blowdown gas into the engine fuel system. The following discussion highlights the verification issues for each case and outlines measurements and data collection activities implemented in the verification test.

2.3.1.1 Case 1

Case 1 represents a compressor that normally maintains full operating pressure during idle periods. For this case, a change in emissions was anticipated to occur only at the rod packing due to the static sealing action of the Emissions Packing. To quantify this potential change in rod packing leaks, direct methane emission rate measurements were conducted on the distance piece or doghouse vent pipes associated with the Control Rods and Test Rods for each of the two engines. Because the unit pressure is essentially unchanged during both operating and idle periods, leak rates from all other components (pressure relief valve, blowdown valve, unit valves, and miscellaneous flanges, valves, and fittings) can be assumed to remain constant after installation of the Emissions Packing. The idle-mode emissions from the two Control Rods are compared to idle-mode emissions from the two Test Rods. The difference between these two values are determined, and used to quantify the static sealing abilities of the Emissions Packing.

For Case 1, the savings consist solely of the gas prevented from leaking from the rod packing during idle periods. This is the difference between the leak rate without the Emissions Packing (measured for the Control Rods) and the leak rate with the Emissions Packing (measured for the Test Rods). Equation 1 states how gas savings will be calculated.

$$\mathbf{G1 = [Q_u - Q_s] * t} \qquad \text{(Eqn. 1)}$$

where,

G1 = average gas savings for the Phase I test period (Case 1), scf
Q_u = average uncontrolled leak rate during idle (Control Rod), scfm
Q_s = average controlled leak rate during idle (Test Rod), scfm
t = total shutdown or idle time during Phase I, minutes

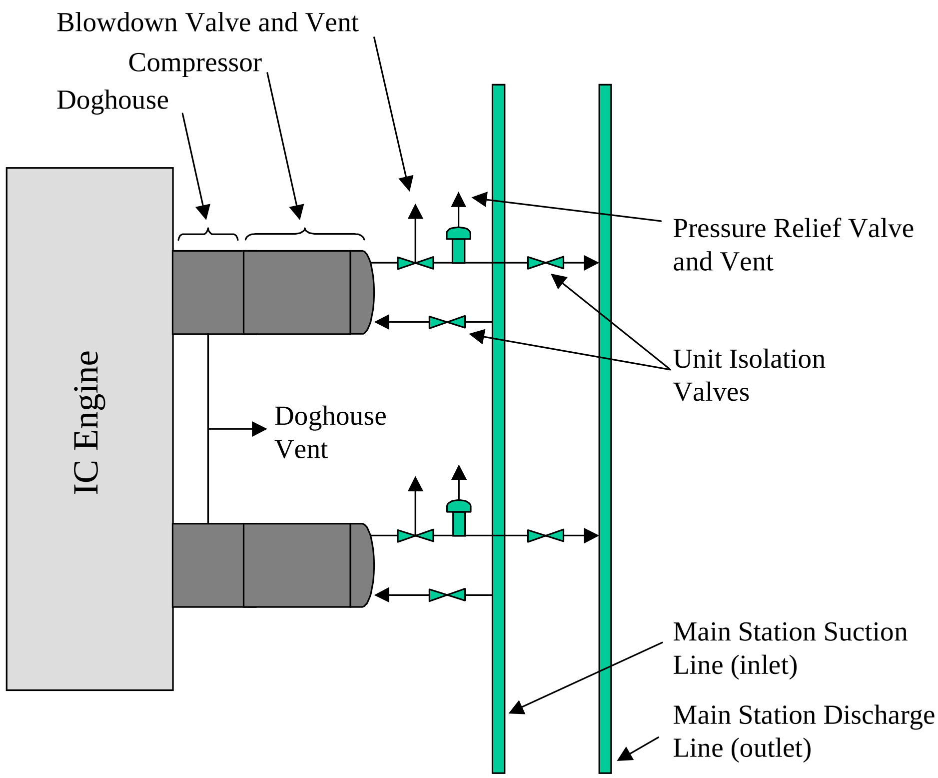
Table 2-1. Common Shutdown Scenarios and Emissions		
Matrix of Shutdown Procedure Changes		
Procedure or emission source	**CASE 1**	**CASE 2**
Current shutdown procedure	Pressurized shutdown with unit valves open or closed[a]	Blowdown/100% vent to atmosphere
Procedure with Emissions Packing	n/c	Pressurized shutdown
Matrix of Possible Emissions Changes Due to Shutdown Procedure Changes or Installation of the Emissions Packing		
Rod seals	Decrease	Little or no increase
Blow-down volume	n/c[b]	Decrease
Unit valve seat (via open blow-down line)	n/c	Decrease
Blow-down valve	n/c	Increase
Pressure relief valve	n/c	Increase
Misc. valves, fittings, flanges, stems etc.	n/c	Increase

[a] Most sites leave the unit valves closed for safety reasons (i.e., sites may not want problems in the shutdown engine to affect the integrity of the entire station).
[b] n/c - no change/effectively no change
Shaded area represents measured parameters.

2.3.1.2 Case 2

Case 2 represents a compressor that normally blows down from operating pressure to a minimum pressure during idle periods. At such times the pressure on compressor components is reduced to near atmospheric pressure. Consequently, leaks from rod packing, pressure relief valves, and blowdown valves cease to exist. However, leaks from the unit valves, which are closed to isolate the compressor from the pipeline, are liberated into the atmosphere. This gas leaks past the unit valves, into the compressor system, and out into the atmosphere via the open blowdown valve. Figure 2-2 illustrates a simplified diagram of these emission sources. Because emissions associated with leaking unit valves can be substantial, measurements were made to quantify these emissions after blowdown was completed. When the Emissions Packing is installed, and a pressurized shutdown eliminates the unit valve leaks, this gas represents a saving associated with the use of the Emissions Packing. In addition, the compressed gas contained in the compressor and lines is lost during the blowdown. This gas must also be considered as a savings associated with the Emissions Packing, and was calculated based on known volumes of compressor components and the measured operating pressure. All of these emission savings are added to the savings determined for the rod packing as described above, resulting in a total gas savings value for the Emissions Packing.

Figure 2-2. Compressor/Engine Configuration and Emissions Sources



In contrast, emissions can increase from several components which are now exposed to high pressure. Ultimately, these leaks decrease the net gas savings associated with the Emissions Packing. To verify this, methane emission rate measurements were conducted (during pressurized idle mode) on all components newly exposed to elevated pressures as a result of the pressurized shutdown. These compounds include the pressure relief valve, the blowdown valve, and various flanges, connectors, and valves. Emissions from these devices are subtracted from the total savings above, to yield the net savings associated with the Emissions Packing.

It is assumed that, following installation of the Emissions Packing and after a pressurized shutdown is adopted, the unit valve would be placed in a closed position during shutdown (this was the host site's procedure). Compressor pressures were monitored during shutdown to determine if the pressure slowly dropped due to this closed valve, or if leaks from the closed valve were sufficient to maintain full compressor pressure.

For Case 2, gas savings consist of the blowdown volume (times the number of idle periods) and the unit valve leak rate (times the duration of idle periods). In addition, there are gas leakages from the blowdown valve, pressure relief valves, and miscellaneous components. Additionally, any gas that escapes past the Emissions Packing is lost (because the baseline for this case is a blowndown compressor, rod packing leakage would be zero). For Case 2, the gas savings for each idle period were calculated as follows.

$$G2 = BDV + Q_{uv} * t - [Q_{prv} + Q_{bdv} + Q_{misc} + Q_s] * t \quad \text{(Eqn. 2)}$$

where,

$G2$ = gas savings for each idle period (Case 2), scf
BDV = blowdown volume times the number of blowdowns during the Phase I period, scf
Q_{uv} = unit valve leak rate, scfm
t = idle time over the Phase I test period, minutes
Q_{prv} = pressure relief valve leak rate, scfm
Q_{bdv} = blowdown valve leak rate, scfm
Q_{misc} = aggregate leak rate for miscellaneous components, scfm
Q_s = test rod leak rate, scfm

2.3.1.3 Impact on Normal Running Emissions

With the Emissions Packing technology, several standard sealing rings are replaced with special France rings and pressure plates. With this change, there is a potential to alter the emission sealing performance of the overall packing system (i.e., cause an increase or decrease in packing emissions compared to the standard packing). To address this, measurements were conducted on the test and control rods, with the compressors in a normal operating state. It is assumed that, after installation of the Emissions Packing, the unit valve position (i.e., closed or open) would remain the same as before the Emissions Packing was installed. Any implied running emission changes were integrated into the assessment of net gas savings for the Emissions Packing system.

For example, if it was determined that the Emissions Packing caused any increase in emissions during normal compressor operation (see later discussion on running emissions), these emissions were subtracted from the gas savings. The following equation states how the total gas savings will be calculated for each case. The total gas savings, $G1_T$ and $G2_T$, for Case 1 and Case 2, respectively, are given in Equations 3a and 3b.

$$G1_T = G1 - V_m \quad \text{(Eqn. 3a)}$$

$$G2_T = G2 - V_m \quad \text{(Eqn. 3b)}$$

Where, V_m is any increase in operating emissions that occurred over the test period due to the Emissions Packing. V_m is the difference in operating emissions (i.e., non-idle periods) between the Test and Control Rods, times the number of minutes the compressor operated during the Phase I test period.

2.3.2 Emission Measurements and Calculations

The following discussion provides an overview of the measurements made, instruments used, field procedures followed, and key calculations made in the Phase I tests. For more detail on these topics, the reader should consult the Test Plan titled *Testing and Quality Assurance Plan for the France Compressor Products Emissions Packing* (SRI 1999). It can be downloaded from the Center's Web site at www.sri-rtp.com.

To characterize the running emissions and Case 1/Case 2 emissions, manual emission measurements were collected on the following sources: doghouse vent, unit valve seat (via the open blowdown line), pressure relief valve vent, blowdown valve vent, and miscellaneous components (e.g., fittings, connections, valve stems). Tests were performed when the engine was pressurized and running, pressurized and idle, and depressurized and idle. For the rod packing leaks, tests were performed when the engine was pressurized and running, and pressurized and idle. Measurements of the leak rate for the blowdown valve, pressure relief valve, and miscellaneous other components were made when the unit was pressurized and idle. The unit valve leak rate measurement was made with the unit blowndown and the blowdown valve closed.

The measurements made and operating conditions under which testing was performed are listed below. One full day was required to conduct this suite of measurements on both engines.

- With both units shut down and pressurized: natural gas leak rates for the pressure relief valve, blow down valve, miscellaneous components, and rod packing vents (test rod and control rod)

- With both units blown down: natural gas leak rates for the unit valve and unit valve stem

- With both units running: natural gas leak rates for the doghouse vents (Test Rod and Control Rod)

Measured natural gas leak rates were converted to methane leak rates using natural gas compositional measurements (about 97 percent methane) provided by ANR Pipeline.

The station agreed to a limited number of scheduled shutdowns for the purpose of conducting the measurements described above. Results from these tests were used to characterize emission rates at the time of testing, and to characterize emissions differences between Case 1 and 2 above. Net gas savings were calculated based on the number and duration of idle periods encountered at the site for the test period.

2.3.2.1 Rod Leak Rate Measurements

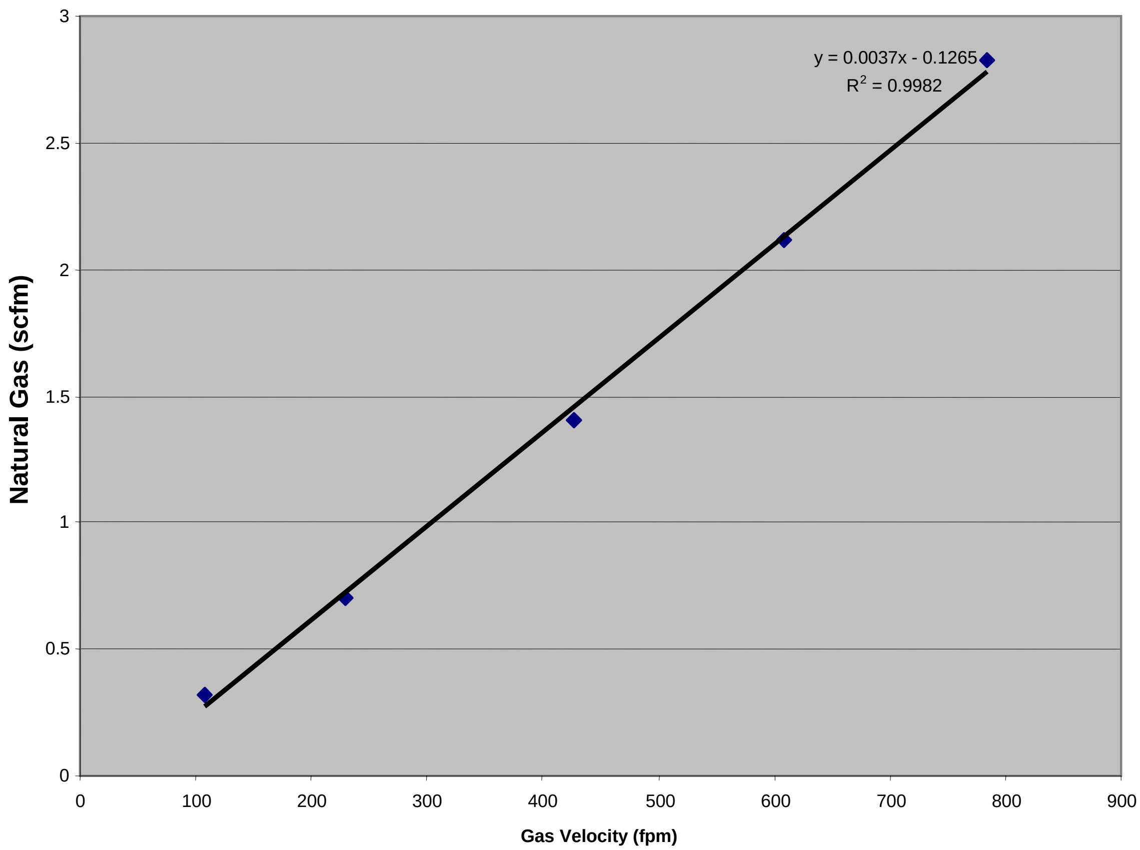
Emissions from the packing case vent and leaking rod seals are both vented into the distance piece or doghouse described in Section 1.2. Both emission sources vent gas that has escaped the sealing action of the packing, and are included together when measuring emissions. After emissions are discharged into the doghouse, they are vented to the atmosphere through the doghouse vent. After soap screening all doghouse seals and connections and monitoring the long-term compositional trends of the gas exiting the doghouse, it was determined that no other gas was entering the doghouse. The doghouse vent and oil drain were the only paths by which emissions escaped into the atmosphere. For the test, the doghouse oil drain was sealed using a liquid trap (ball valves closed during testing), which forced all emissions to exit through the doghouse vent.

To measure these emissions, a Flow Tube was used to measure vent gas velocity, and a hydrocarbon analyzer was used to measure vent gas total hydrocarbon concentration (THC) before flow measurement started. In the original Test Plan, sensitive, low-pressure-drop continuous flow meters were planned for use, but after their installation, it was determined that the pressure in the doghouse vents was so low that reliable flow detection could not be established. With this discovery, the decision was made to proceed with testing, and to use sensitive manual methods to conduct the measurements.

The Flow Tube consists of a sensitive 1-inch vane anemometer mounted on the inside walls of a polyvinyl chloride (PVC) tube that measures 30 inches in length and 1 inch in diameter. Just before taking velocity readings, the hydrocarbon concentration in the doghouse vent was measured using a portable hydrocarbon analyzer. The analyzer used was a Bascom-Turner CGI-201, with a 4-100 percent total hydrocarbon range, and an instrument rated accuracy of 2 percent (per manufacturer specifications) of the measured concentration. The CGI-201 measures all primary hydrocarbon compounds found in natural gas including methane, ethane, propane, and butane.

Before each trip to the site for on-site measurements, the Flow Tube was laboratory-calibrated using a National Institute of Standards and Technology (NIST) traceable Laminar Flow Element and a wide range of simulated natural gas flow rates (99 percent methane, 0.3 to 4 scfm). These calibrations were used to generate a calibration curve which spanned the range of flow rates anticipated for the site. This curve was used to select a natural gas flow rate based on the indicated velocity from the flow tube. An example calibration chart is shown in Figure 2-3.

Figure 2-3. Flow Tube Calibration at Low Flows (6/2/99)



For each doghouse vent, a minimum of 10 separate gas velocity readings were recorded with the Flow Tube. These measurements were made after the doghouse emissions were observed to stabilize (15 to 20 minutes after the vents were opened). The standard deviation of the doghouse emissions ranged between 0.0042 and 0.0680 scfm natural gas. The standard deviation over 70 percent of the samples collected was within the average standard deviation of 0.0042 scfm. In most cases, the 10 readings showed stable emissions. More readings were collected if the standard deviation was greater than 5 percent of the average emission rate of the entire data set. Each measurement represents a 16-second average value and, after completion, all values were averaged to yield an overall average total gas flow rate in feet per minute. Using this value, a natural gas flow rate was selected from the flow tube calibration curve.

It should be noted that, after opening the doghouse vent for measurement, air typically enters and mixes with the natural gas leaking from the rod packing. The average THC content in the gas flows measured at the Control Rod was 85 percent, and at the Test Rod was 91 percent (during running and idle periods). Based on the Center's experience with characterizing doghouse vent emissions at several compressor facilities, it is believed that the rod packing leak is the driving force which results in gas escaping through the vents (i.e., only one outlet stream is present for the gas to escape and no other gas can enter the doghouse). As such, it is assumed that the flow rate measured during testing is representative of the flow rate of pure natural gas. Also, given a sufficient amount of time, the rod leaks would eventually completely purge all air from the doghouse, allowing direct measurement of pure natural gas with the flow tube. As a practical matter, this could not be done routinely. This assumption was verified by monitoring composition on two vents over time (about 1 hour), and verifying that the composition eventually reached 92 to 94 percent THC.

2.3.2.2 Component Leak Rate Measurements

Manual measurements were made for the pressure relief valves, unit valves, blowdown valves, and miscellaneous components. The leak rates for the blowdown valve and pressure relief valve were measured with the unit shut down and pressurized. Measurements for miscellaneous components were also made with the unit pressurized. Leak rates for the unit valves were determined with the unit depressurized and the valve closed.

The pressure relief valves vent through a 6-inch standpipe extending to the roof of the compressor building. Access to the roof was limited, and posed a hazard to the testing personnel. Thus, a hydrocarbon analyzer was first used to determine if leaks were present. If hydrocarbons were detected, the Flow Tube was to be used to quantify gas flow rates. With the exception of making a direct connection to the 6-inch standpipe outlet, the sampling and calibration procedures described in the previous section apply to this emission source as well.

Flow measurements were conducted at an existing port, located immediately downstream of the unit valves in the suction line of each compressor. During compressor shutdown, any leaks from the seats of the unit valves will exit through this opened port. The leak rate for the unit valves was the highest flow measured at the host site. The leak rate was measured using the same Flow Tube applied to the rod packing vents. The anemometer mounted within the tube has the capacity to measure the high flows that occurred (e.g., a maximum of 6,500 fpm or about 20 cfm of natural gas could be measured). However, a different calibration chart from the one presented in Figure 2-3 was used to determine emission rates at the higher flows encountered with unit valves leaks (see Section 4 for more information on calibration).

The leak rate for the blowdown valve was measured at the flange located at the exit of the valve. To make this measurement, it was necessary to unbolt the flange, separate the two sides by about 1 inch, and then insert a disk. The disk contained channels that allowed the leak to be captured and directed into a small, sensitive low-flow-rate rotameter (Dwyer VB Series, 0 to 1000 mL/min, with a published accuracy and precision $\pm$3 percent). The Flow Tube was originally planned for use on the blowdown valve emissions, but early field results indicated relatively low flow rates existed at this location. The low-flow-rate rotameter was used because of the poor performance of the Flow Tube at these low flows.

The miscellaneous components at the test site consist of pressure and temperature metering taps, fittings that connect the taps to data transmitters, and valves used to recover gas for the fuel recovery system. The host station normally vents to a specially designed gas recovery system during shutdown, but performed the blowdown procedure for this verification, allowing an assessment of the Case 1 and Case 2 shutdown scenarios described above. Significant leaks were not expected at these locations; however, all components were soap screened and any leaks identified were to be quantified using the EPA protocol tent/bag method.

2.3.2.3 Natural Gas Composition Measurements

Natural gas compositional analysis for the test site is performed at an adjacent compressor station operated by ANR Pipeline Company (about 70 miles downstream). At this site ANR operators use a gas chromatograph (Daniel Model #2251) to determine the concentration of methane, hydrocarbons, and inert gas species present in the pipeline gas. The gas chromatograph is capable of measuring 0 to 100 percent methane, with a published accuracy and precision of $\pm$0.02 percent of full range. The instrument is calibrated each month using 97.0 percent certified methane.

The Center obtained copies of the fuel gas analyses results and their calibration records which correspond to the Phase I measurements. An average methane concentration was calculated for those days when sampling was conducted. This value was multiplied by the natural gas savings measured for each case to calculate the standard cubic feet of methane saved.

2.3.2.4 Blowdown Volume Determination

The blowdown volume represents gas contained in the test compressor, engine, auxiliary piping, and all components located downstream of the unit valves. Based on records obtained from ANR, the total gas volume present in this equipment is 176 cu ft. ANR engineers determined that at 600 psig pressure, 7,900 scf natural gas occupies this volume (corrected for the compressibility factor). Because it is not feasible to directly measure the blowdown volume, 7,900 scf was used to represent the total gas that would be released into the atmosphere each time the test compressor was depressurized from 600 to 0 psig.

2.3.3 Site Operational Data

The number and duration of shutdown/idle periods must be specified to calculate the gas savings that occurred during the 4-week Phase I evaluation. Site records, provided by ANR pipeline, were used to determine the number and duration of shutdowns for the Phase I period. The ANR records identify daily compressor operating hours and the total hours the compressor was available (i.e., scheduled shutdown for maintenance is not included in the available hour values). Subtraction of the total available hours from the total operating hours yields the number of hours each unit was on idle. Because the number and duration of shutdowns were manipulated by the Center to ensure collection of the necessary measurements, those shutdowns that occurred at the Center's request were also subtracted.

The number of blowdowns was determined by accounting for each occurrence of an idle period. (It should be noted that this is an estimated value because the test site does not normally blow down, but rather, maintains a minimum pressure of 120 psig operating pressures during idle periods.) The number of blowdown occurrences assigned for the Case 2 evaluation is a synthetic value which represents sites that follow blowdown procedures.

3.0 RESULTS

3.1 ROD PACKING EMISSIONS

3.1.1 Emissions During Idle/Shutdown

Doghouse leak rate measurements data were collected over a 7- day sampling period. These data span the range of time from when both the Emissions Packing and the conventional packing were new until they had logged about 1100 hours of wear. Table 3-1 presents the measured packing vent emissions for Engines 501 and 502 during pressurized idle states. The results are summarized as differences. A 95 percent confidence interval about the mean of the differences was computed based on a Student's t distribution. Measurements were generally started 20 minutes after shutdown occurred, unless the engine had been shut down overnight. It generally required about 30 minutes to complete the data collection. For 80 percent of the samples, the engine was in the idle mode for at least 24 hours (see footnote d in Table 3-1). No changes in rod emission rates were observed between measurements made shortly after shutdown and after a minimum of 24 hours had transpired.

Table 3-1 shows that the France packing did not reduce compressor rod packing leaks during the standby idle mode. The average difference (both engines) between the Control Rod and Test Rod was -0.29 ±0.55 scfm natural gas. Thus, at the 95 percent confidence level, there is a slight negative difference between sealing performance with and without the emissions packing. The errors calculated using the Student's t distribution are greater than the errors expected from the measurement instruments, showing process variability between the two rods.

Of the 14 samples collected, 10 measurements showed a loss in gas savings between the Emissions Packing and the conventional packing, although the differences were small in some cases. Averaging the data from both engines, the overall average emission rate for the France Packing Rod was 1.23 ± 0.54 scfm while the Control Rod overall average emissions rate was 0.94 ± 0.39 scfm.

For Engine 501, the Test Rod emitted slightly more gas than the Control Rod (-0.54 ± 0.47 scfm natural gas). For Engine 502, the France packing emissions were initially lower than the conventional packing, but halfway through the Phase I test period, they increased and remained higher than the conventional packing (see Figure 3-1). On average, no reduction in rod emissions was detected on Engine 502 (-0.04 ± 0.55 scfm), indicating that the Emissions Packing did not reduce idle emissions as expected.

Although not confirmed, the differences between Engines 501 and 502 emissions may be the result of different rod materials (see footnote a to Table 3-1). As Figure 3-1 illustrates, it appears that emissions from Engine 502 are slightly higher than from Engine 501. The figure also suggests that the France packing emissions were more variable, while the emissions for the conventional packing were relatively stable. No clear emission trends are apparent, but it can be concluded that the France Packing does not perform significantly better (as expected) than the conventional packing during idle periods.

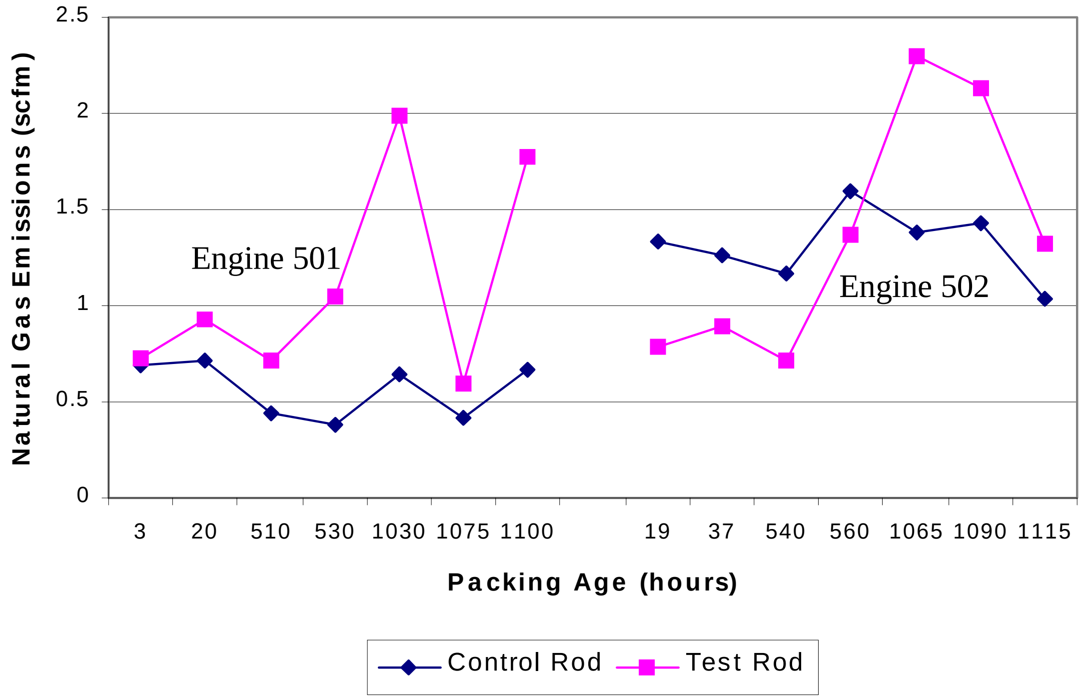
Table 3-1. Rod Seal Emissions of Natural Gas (Unit Idle & Pressurized)				
Date	**Approx. Run Time on New Seals (hrs)**	**Engine Idle, Pressurized @ 600 psi**		**Difference Between Control Rod and Test Rod[b] (scfm natural gas)**
		Control Rod With Conventional Packing (scfm natural gas)	**Test Rod With Emissions Packing[a] (scfm natural gas)**	
ENGINE 501				
6/16/99[d]	3	0.69	0.73	-0.04
6/17/99[d]	20	0.72	0.93	-0.21
7/7/99	510	0.44	0.71	-0.27
7/8/99	530	0.38	1.05	-0.67
7/28/99[d]	1030	0.64	1.99	-1.35
7/29/99[d]	1075	0.42	0.59	-0.17
7/30/99[d]	1100	0.67	1.77	-1.10
	Average	0.57	1.11	-0.54
	Confidence Coefficient[c]	±0.13	±0.51	±0.47
ENGINE 502[a]				
6/16/99[d]	19	1.33	0.78	+0.55
6/17/99[d]	37	1.26	0.89	+0.37
7/7/99[d]	540	1.17	0.71	+0.46
7/8/99	560	1.59	1.37	+0.22
7/28/99[d]	1065	1.38	2.30	-0.92
7/29/99[d]	1090	1.43	2.13	-0.70
7/30/99[d]	1115	1.04	1.32	-0.28
	Average	1.31	1.36	-0.04
	Confidence Coefficient[c]	±0.17	±0.59	±0.55
Both Engines Combined				
	Average	0.94	1.23	-0.29
	Confidence Coefficient[c]	±0.39	±0.54	±0.55

[a] The Test Rod on Engine 502 is ceramic coated. The remaining rods are alloy steel.
[b] Difference = (Control Rod Emissions - Test Rod Emissions), positive values indicate gas savings was achieved.
[c] Student's t distribution statistical analysis was used. Results are reported at 95% confidence level.
[d] The test engines were on idle standby mode for at least 24 hours prior to sampling.

3.1.2 Emissions During Compressor Operation

Table 3-2 presents the measured packing vent emissions for Engines 501 and 502 during compressor operation. As before, seven daily average natural gas emission rates are reported for each vent, and these data span the range of time from when the packing was new, until the packing had logged about 1100 hours of wear. Measurements were collected after emissions had stabilized (generally within 5 to 15 minutes after the engine was loaded).

Figure 3-1. Idle-Mode Emissions



As was the case with the idle-mode emissions, the France packing generally had emissions that were slightly higher than the conventional packing during operation, although the differences were not as great. For Engine 501, the France packing had emissions that were 0.03 to 0.59 scfm higher than the conventional packing (an average increase of 0.25 $\pm$ 0.21 scfm). On Engine 502, the France packing emissions were initially lower, but halfway through the Phase I period, they became higher for a time and then decreased again. For Engine 502, the differences between the France packing and the conventional packing ranged from 0.54 to +0.54 scfm, with an average savings of 0.15 $\pm$ 0.44 scfm.

Averaging the data from both engines, the France packing produced overall average emissions that were 1.04 $\pm$ 0.41 scfm while the Control Rod emissions were 0.99 $\pm$ 0.40 scfm. Running emissions were 0.05 $\pm$ 0.38 scfm higher than the conventional packing (about 3 percent higher than the Control Rods). Based on these data, it can be concluded that the removal of the seal required to install the France packing may result in slightly higher emissions while the compressor is operating, although the differences are relatively insignificant compared to the rod emission rates.

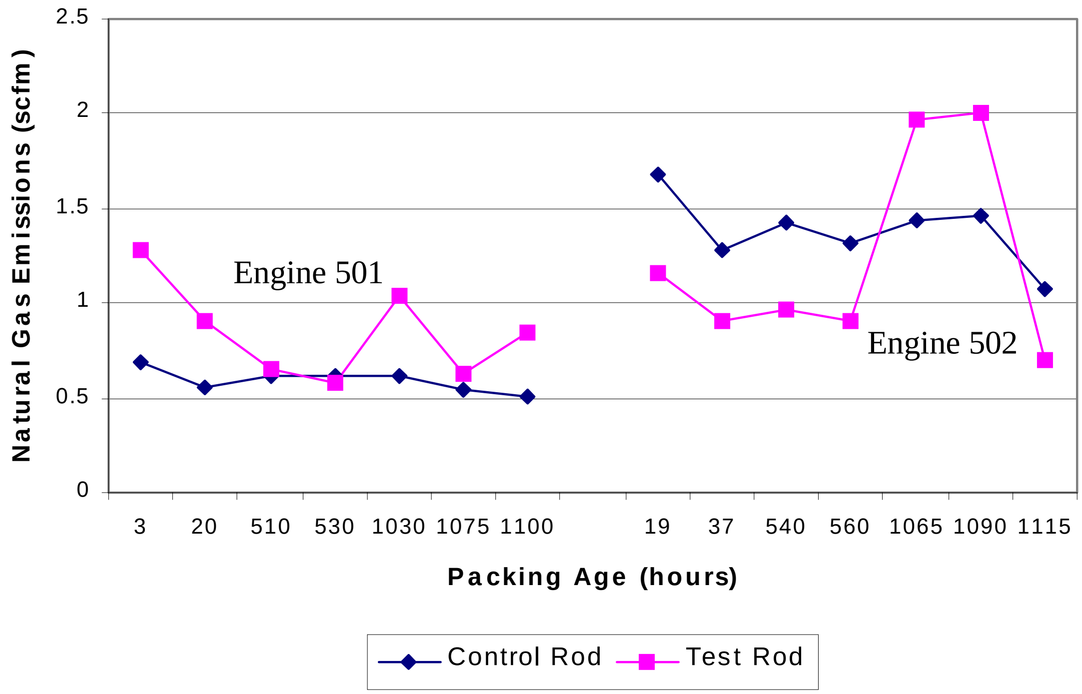
Figure 3-2 presents a plot of the running emissions for both engines. As the figure suggests, emissions from the France packing are less variable than the conventional packing when the compressor is in the operating mode, and the difference between the conventional and France packing is also reduced. The figure also suggests that no clear emission trends are apparent.

Table 3-2. Rod Seal Emissions of Natural Gas (Unit Operating)

Date	Approx. Run Time on New Seals, hrs	Engine Running @ 600 psi: Control Rod With Conventional Packing, scfm natural gas	Engine Running @ 600 psi: Test Rod With Emissions Packing[a], scfm natural gas	Difference Between Control Rod and Test Rod[b], scfm natural gas
ENGINE 501				
6/16/99	3	0.69	1.28	-0.59
6/17/99	20	0.55	0.90	-0.35
7/7/99	510	0.62	0.65	-0.03
7/8/99	530	0.61	0.58	+0.03
7/28/99	1030	0.62	1.04	-0.42
7/29/99	1075	0.54	0.63	-0.09
7/30/99	1100	0.51	0.84	-0.33
	Average	0.59	0.85	-0.25
	Confidence Coefficient[c]	±0.06	±0.23	±0.21
ENGINE 502[a]				
6/16/99	19	1.68	1.16	+0.52
6/17/99	37	1.28	0.90	+0.38
7/7/99	540	1.43	0.97	+0.46
7/8/99	560	1.32	0.91	+0.41
7/28/99	1065	1.44	1.97	-0.53
7/29/99	1090	1.46	2.00	-0.54
7/30/99	1115	1.08	0.70	+0.38
	Average	1.38	1.23	0.15
	Confidence Coefficient[c]	±0.17	±0.49	±0.44
Both Engines Combined				
	Average	0.99	1.04	-0.05
	Confidence Coefficient[c]	±0.40	±0.41	±0.38

[a] The Test Rod on Engine 502 is ceramic coated. The remaining rods are alloy steel.
[b] Difference = (Control Rod Emissions - Test Rod Emissions), positive values indicate gas savings are achieved.
[c] Student's t distribution statistical analysis was used. Results are reported at 95% confidence level.

Figure 3-2. Operating Emissions



3.2 OTHER EMISSION SOURCES

3.2.1 Valve Leaks and Blowdown Volume

Measurements were conducted to quantify emissions associated with the closed and pressurized blowdown valve, pressure relief valve, and unit valves. These measurements represent the emissions leaking past the valve seats on each device. Estimates of the emissions associated with compressor blowdown operations are also presented, and are based on ANR-supplied gas pressures and equipment volumes. The sources addressed in this section are among the most significant fugitive emission sources associated with compressor operations. Measurements associated with the remaining minor sources (e.g., valve stems, fittings, and other minor fugitive sources) are addressed in Section 3.2.2.

Measurement results are presented in Table 3-3. As the table shows, screening with the hydrocarbon analyzer showed that no gas was leaking from the pressure relief valve. Thus, a flow rate of 0 scfm is assigned here. Emissions from the unit valve were high and relatively variable. The overall average emission rate was 12.14 scfm, which excludes three low emission rates that occurred when operators took action to reduce emissions in response to the measurements data collected (see footnote b in Table 3-3). The blowdown volume is constant because the operating pressure and equipment volume remained the same.

Table 3-3. Component Emissions				
Date	**Blowdown Valve (scfm gas)**	**Pressure Relief Valve (scfm gas)**	**Unit Valve (scfm gas)**	**Blowdown Volume[a] (scf gas/event)**
ENGINE 501				
6/16/99	0.16	0[d]	0.00[b]	7,900
6/17/99	0.16	0[d]	1.46[b]	7,900
7/7/99	0.07	0[d]	12.05	7,900
7/8/99	0.07	0[d]	12.51	7,900
7/28/99	0.06	0[d]	17.50	7,900
7/29/99	[c]	0[d]	16.55	7,900
7/30/99	0.03	0[d]	19.44	7,900
ENGINE 502				
6/16/99	0.14	0[d]	10.00	7,900
6/17/99	0.14	0[d]	3.09[b]	7,900
7/7/99	0.04	0[d]	6.21	7,900
7/8/99	0.04	0[d]	6.61	7,900
7/28/99	0.04	0[d]	12.70	7,900
7/29/99	[c]	0[d]	10.96	7,900
7/30/99	0.01	0[d]	9.06	7,900

[a] Based on calculations performed by ANR engineers. This value represents the total volume of gas present in the test compressor, piping, and all equipment located downstream of the unit valves (at 600 psig).
[b] The station operator greased the unit valve to reduce emissions. This process temporarily reduced the leakage, and is not considered representative.
[c] The Center field operator mistakenly measured the blowdown valve emissions while the unit was pressurized at 120 psig, instead of 600 psig. Blowdown valve emissions are not reported for this day.
[d] A hydrocarbon analyzer was first used as a screening method to identify if leaks were present. If THC levels were found to be greater than 50 percent, the Flow Tube was required to be used to quantify the leak rate. For these samples, THC levels were nearly 0 percent. Thus, the Flow Tube was not used.

3.2.2 Miscellaneous Fugitive Sources

Once each day, miscellaneous fugitive emission sources were soap-screened to identify components that were leaking significantly and in need of emission rate measurement. The types of components screened are identified below.

- Flanges – Valve, meter, pipe, and other flanges
- Miscellaneous fittings (tees, elbows, couplings, drains, ports, small valves)
- Blowdown gas recovery system components
- Temperature and pressure metering ports

The soap-screening revealed no leaking components. This is not surprising, because most of these components are located in confined working areas, and any leaks could result in a significant safety hazard or triggering of the gas detection alarm system located at the site.

3.3 NET GAS SAVINGS

The primary verification parameter determined for the Phase I evaluation is net gas savings. The Phase I test period began after the packings were installed and the engines were started (June 16, 1999), and ended on the last day of sampling (July 30, 1999). Net gas savings for the Phase I period were calculated for the Case 1 and Case 2 baseline shutdown scenarios based on the overall average emission rates presented in Sections 3.1 and 3.2 and engine operational data presented in the next section. For Case 1, the use of Emissions Packing resulted in a gas loss of -18,224 ± 29,987 scf for the two test engines. For Case 2, the net gas savings for both test engines were determined to be 651,261 ± 47,775 scf. The gas savings achieved here are due to the change in operating practice, not the Emissions Packing. The following subsections discuss these results in detail.

3.3.1 Compressor Operational Characteristics

To calculate net gas savings, the operational characteristics of both engines were defined on a daily basis. The operating characteristics of interest include the number of shutdowns, the number of hours in the idle mode, the number of hours in the running or operating mode, and the number of hours in the out-of-service mode (i.e., non-idle mode such as maintenance and repair). These operating characteristics, presented in Table 3-4, were defined for Engines 501 and 502 using data supplied by ANR Pipeline. The gray areas in the table correspond with sampling conducted by the Center. Although several idle-mode shutdowns occurred on these days, they are not included in the determination of gas savings because these shutdowns were performed at the request of the Center.

3.3.2 Case 1 and Case 2 Gas Savings

This section presents calculated gas savings associated with the France packing for Engines 501 and 502. Savings are computed by comparing compressor emissions when the France packing is installed with compressor emissions without the France packing. The France packing requires a pressurized shutdown/idle mode be used, and the gas savings achieved will depend on how shutdown and idle mode operations were managed prior to installing the France packing.

Two base-case shutdown/idle modes are assumed. Case 1 represents the original use of a pressurized shutdown (same as the Emissions Packing requires) and Case 2 represents the original use of compressor depressurization and blowdown. As a result of changing the packing, and possibly the shutdown/idle mode, a variety of emission changes will occur in both cases. Each change is quantified here, and the bullets below describe how each value is calculated. The emission factors referred to below were described in Sections 3.1 and 3.2, and are summarized in Table 3-5.

Table 3-4. Engine Operating Schedule for Phase I					
Engine	**Date**	**Number of Shutdowns**	**Operational Data (Hrs)**		
			Running	**Scheduled Downtime for Maintenance, etc.**	**Idle**
501	16-Jun				
	17-Jun				
	18-Jun		9.9	0	14.1
	19-Jun		24	0	0
	20-Jun		24	0	0
	21-Jun		24	0	0
	22-Jun		24	0	0
	23-Jun		24	0	0
	24-Jun		24	0	0
	25-Jun		24	0	0
	26-Jun		24	0	0
	27-Jun		24	0	0
	28-Jun		20.3	3.7	0
	29-Jun		24	0	0
	30-Jun		24	0	0
	1-Jul		24	0	0
	2-Jul		24	0	0
	3-Jul		24	0	0
	4-Jul	1	7.4	0.1	16.5
	5-Jul		4.2	0.2	19.6
	6-Jul		24	0	0
	7-Jul				
	8-Jul				
	9-Jul		24	0	0
	10-Jul		15.7	8.3	0
	11-Jul	1	0	17	7
	12-Jul		0	0	24
	13-Jul		0	0	24
	14-Jul		0	0	24
	15-Jul		0	0	24
	16-Jul		6.4	6.8	10.8
	17-Jul		0	24	0
	18-Jul		0	24	0
	19-Jul	1	0	7.7	16.3
	20-Jul		0	0	24
	21-Jul		0	0	24
	22-Jul		0	0	24
	23-Jul		0	0	24
	24-Jul		0	0	24
	25-Jul		0	0	24
	26-Jul		0	0	24
	27-Jul		0	0	24

(continued)

Table 3-4 (continued)

Engine	Date	Number of Shutdowns	Operational Data (Hrs)		
			Running	Scheduled Downtime for Maintenance, etc.	Idle
	28-Jul				
	29-Jul				
	30-Jul				
TOTAL		3	447.9	91.8	372.3
502	16-Jun				
	17-Jun				
	18-Jun	1	0.7	0	23.3
	19-Jun		0	0	24
	20-Jun		0	0	24
	21-Jun		0	1.2	22.8
	22-Jun		9.4	5.9	8.7
	23-Jun	1	18.5	0.1	5.4
	24-Jun		0	0	24
	25-Jun		0	0	24
	26-Jun		0	0	24
	27-Jun		0	0	24
	28-Jun		0	9.1	14.9
	29-Jun		10.4	0.3	13.3
	30-Jun		24	0	0
	1-Jul		24	0	0
	2-Jul		24	0	0
	3-Jul		24	0	0
	4-Jul	1	10.4	0.1	13.5
	5-Jul		0	0	24
	6-Jul		0	0.4	23.6
	7-Jul				
	8-Jul				
	9-Jul		21.8	0.1	2.1
	10-Jul		0	0	24
	11-Jul		0	0	24
	12-Jul		0	0	24
	13-Jul		8.3	0.2	15.5
	14-Jul		24	0	0
	15-Jul	1	10.8	0.1	13.1
	16-Jul		13	1.8	9.2
	17-Jul		24	0	0
	18-Jul		24	0	0
	19-Jul		24	0	0
	20-Jul		24	0	0
	21-Jul		24	0	0
	22-Jul	1	12.9	0.1	11
	23-Jul		0	0	24
	24-Jul		0	0	24

(continued)

Table 3-4 (continued)

Engine	Date	Number of Shutdowns	Operational Data (Hrs)		
			Running	Scheduled Downtime for Maintenance, etc.	Idle
	25-Jul		0	0	24
	26-Jul		0	0	24
	27-Jul		0	0	24
	28-Jul				
	29-Jul				
	30-Jul				
TOTAL		5	356.2	19.4	536.4
Note: Gray areas represent sampling conducted by the Center.					

CASE 1 (no change in shutdown/idle mode; i.e., pressurized shutdown/idle continues):

- Rod seal savings while idle:
  Description: Rod packing emissions that are reduced by the France packing during idle periods
  Calculation: Idle hours(Control Rod emission factor - Test Rod emission factor)*
- Rod seal losses due to emissions increases while running:
  Description: Rod packing emissions increases caused by the France packing during operation
  Calculation: Running hours(Control Rod emission factor - Test Rod emission factor)*

CASE 2 (change from depressurize/blowdown mode to a pressurized mode):

- Rod seal increases while idle:
  Description: Idle-mode rod packing emissions from France packing (with new pressurized shutdown/idle mode, these emissions must now be added)
  Calculation: Idle hours(Test Rod emission factor)*
- Rod seal losses due to emissions increases while running: same as in Case 1
- Blowdown volume savings:
  Description: Gas contained in the compressor and piping released during shutdown (with new pressurized shutdown/idle mode, these emissions are no longer released)
  Calculation: Number of shutdowns(blowdown volume emission factor)*
- Blowdown valve leak losses:
  Description: Gas released from the closed blowdown valve (with new pressurized shutdown/idle mode, these emissions must now be added)
  Calculation: Idle hours(blowdown valve emission factor)*
- Unit valve leak savings:
  Description: Gas released from the closed unit valves (with new pressurized shutdown/idle mode, these emissions are no longer released)
  Calculation: Idle hours(unit valve emission factor)*
- PRV and miscellaneous component losses
  Description: Gas released from the pressure relief valve and miscellaneous fugitive sources (with new pressurized shutdown/idle mode, these emissions must now be added)
  Calculation: Idle hours(PRV + Miscellaneous components' emission factors = 0)*

Table 3-5. Overall Average Emission Factors (scfm gas)	
Control Rod $_{idle}$	0.94
Test Rod $_{idle}$	1.23
Control Rod $_{running}$	0.99
Test Rod $_{running}$	1.04
Blowdown Volume	7,900 / shutdown
Blowdown Valve	0.08
Unit Valve	12.14
PRV and Misc. Components	0

Table 3-6 presents the gas savings measured and calculated for Case 1 and Case 2. The definitions presented above correspond to specific columns in the table. There are significant differences in gas savings between Engines 501 and 502, but these differences are driven primarily by differences in the number of idle hours that occurred during Phase I. Total natural gas savings for both engines under Case 1 were calculated to be -18,224 ±29,987 scf of natural gas (an overall loss). These gas losses occurred because the France packing did not reduce emissions during idle mode. Total gas savings for both engines under Case 2 were calculated to be 651,261 ± 47,775 scf of natural gas. It should be noted that these savings are not due to the Emissions Packing; rather, the change in operating characteristics provided the added savings. Elimination of the unit valve emissions was the primary factor contributing to the gas savings that occurred in Case 2.

From a greenhouse gas emissions standpoint, the natural gas savings and losses cited above were converted into methane emissions/losses. This was done using natural gas compositional data routinely measured by ANR pipeline (see Section 2.3.2.3). An average 97.09 percent methane composition was measured during the Phase I test period by ANR and, based on this value, total methane reductions (savings) and increases were calculated as follows

Case 1: 7,594 and 10,099 scf methane increase for Engines 501 and 502, respectively
Case 2: 256,587 and 375,723 scf methane decrease for Engines 501 and 502, respectively

Again, the methane reductions for Case 2 occurred as a result of the shutdown/idle process change assumed there; not the performance of the France packing.

3.4 INSTALLATION REQUIREMENTS

Installation of the France packing system was completed in 2 days. Based on interviews conducted with site operators, this is the same amount of time required to install conventional packing. Thus, the incremental installation costs for the France packing is zero. On a per-rod basis, the capital cost was $3,426.42, and the installation required 27 labor-hours.

Table 3-6. Case 1 and Case 2 Gas Savings (scf natural gas)

Engine	Date	CASE 1			CASE 2						
		Rod Seal Savings While Idle	Rod Seal Loss Due to Increase While Running	Total Savings	Rod Seal Increase While Idle	Rod Seal Loss Due to Increase While Running	Blowdown Valve Savings	Blowdown Valve Leak Loss	Unit Valve Leak Savings	PRV and Misc. Comp. Loss	Total Savings
501	16-Jun	0	0	0	0	0	0	0	0	0	0
	17-Jun	0	0	0	0	0	0	0	0	0	0
	18-Jun	-245	-30	-275	-1,041	-30	0	-68	10,270	0	9,132
	19-Jun	0	-72	-72	0	-72	0	0	0	0	-72
	20-Jun	0	-72	-72	0	-72	0	0	0	0	-72
	21-Jun	0	-72	-72	0	-72	0	0	0	0	-72
	22-Jun	0	-72	-72	0	-72	0	0	0	0	-72
	23-Jun	0	-72	-72	0	-72	0	0	0	0	-72
	24-Jun	0	-72	-72	0	-72	0	0	0	0	-72
	25-Jun	0	-72	-72	0	-72	0	0	0	0	-72
	26-Jun	0	-72	-72	0	-72	0	0	0	0	-72
	27-Jun	0	-72	-72	0	-72	0	0	0	0	-72
	28-Jun	0	-61	-61	0	-61	0	0	0	0	-61
	29-Jun	0	-72	-72	0	-72	0	0	0	0	-72
	30-Jun	0	-72	-72	0	-72	0	0	0	0	-72
	1-Jul	0	-72	-72	0	-72	0	0	0	0	-72
	2-Jul	0	-72	-72	0	-72	0	0	0	0	-72
	3-Jul	0	-72	-72	0	-72	0	0	0	0	-72
	4-Jul	-287	-22	-309	-1,218	-22	7,900	-79	12,019	0	18,600
	5-Jul	-341	-13	-354	-1,446	-13	0	-94	14,277	0	12,723
	6-Jul	0	-72	-72	0	-72	0	0	0	0	-72
	7-Jul	0	0	0	0	0	0	0	0	0	0

(continued)

Table 3-6 (continued)

Engine	Date	CASE 1			CASE 2						
		Rod Seal Savings While Idle	Rod Seal Loss Due to Increase While Running	Total Savings	Rod Seal Increase While Idle	Rod Seal Loss Due to Increase While Running	Blowdown Valve Savings	Blowdown Valve Leak Loss	Unit Valve Leak Savings	PRV and Misc. Comp. Loss	Total Savings
	8-Jul	0	0	0	0	0	0	0	0	0	0
	9-Jul	0	-72	-72	0	-72	0	0	0	0	-72
	10-Jul	0	-47	-47	0	-47	0	0	0	0	-47
	11-Jul	-122	0	-122	-517	0	7,900	-34	5,099	0	12,449
	12-Jul	-418	0	-418	-1,771	0	0	-115	17,482	0	15,595
	13-Jul	-418	0	-418	-1,771	0	0	-115	17,482	0	15,595
	14-Jul	-418	0	-418	-1,771	0	0	-115	17,482	0	15,595
	15-Jul	-418	0	-418	-1,771	0	0	-115	17,482	0	15,595
	16-Jul	-188	-19	-207	-797	-19	0	-52	7,867	0	6,999
	17-Jul	0	0	0	0	0	0	0	0	0	0
	18-Jul	0	0	0	0	0	0	0	0	0	0
	19-Jul	-284	0	-284	-1,203	0	7,900	-78	11,873	0	18,492
	20-Jul	-418	0	-418	-1,771	0	0	-115	17,482	0	15,595
	21-Jul	-418	0	-418	-1,771	0	0	-115	17,482	0	15,595
	22-Jul	-418	0	-418	-1,771	0	0	-115	17,482	0	15,595
	23-Jul	-418	0	-418	-1,771	0	0	-115	17,482	0	15,595
	24-Jul	-418	0	-418	-1,771	0	0	-115	17,482	0	15,595
	25-Jul	-418	0	-418	-1,771	0	0	-115	17,482	0	15,595
	26-Jul	-418	0	-418	-1,771	0	0	-115	17,482	0	15,595
	27-Jul	-418	0	-418	-1,771	0	0	-115	17,482	0	15,595
	28-Jul	0	0	0	0	0	0	0	0	0	0
	29-Jul	0	0	0	0	0	0	0	0	0	0
	30-Jul	0	0	0	0	0	0	0	0	0	0
TOTAL		-6,478	-1,344	-7,822	-27,476	-1,344	23,700	-1,787	271,183	0	264,277

(continued)

Table 3-6 (continued)

Engine	Date	CASE 1			CASE 2						
		Rod Seal Savings While Idle	Rod Seal Loss Due to Increase While Running	Total Savings	Rod Seal Increase While Idle	Rod Seal Loss Due to Increase While Running	Blowdown Valve Savings	Blowdown Valve Leak Loss	Unit Valve Leak Savings	PRV and Misc. Comp. Loss	Total Savings
502	16-Jun	0	0	0	0	0	0	0	0	0	0
	17-Jun	0	0	0	0	0	0	0	0	0	0
	18-Jun	-405	-2	-408	-1,720	-2	7,900	-112	16,972	0	23,038
	19-Jun	-418	0	-418	-1,771	0	0	-115	17,482	0	15,595
	20-Jun	-418	0	-418	-1,771	0	0	-115	17,482	0	15,595
	21-Jun	-397	0	-397	-1,683	0	0	-109	16,608	0	14,815
	22-Jun	-151	-28	-180	-642	-28	0	-42	6,337	0	5,625
	23-Jun	-94	-56	-149	-399	-56	7,900	-26	3,933	0	11,353
	24-Jun	-418	0	-418	-1,771	0	0	-115	17,482	0	15,595
	25-Jun	-418	0	-418	-1,771	0	0	-115	17,482	0	15,595
	26-Jun	-418	0	-418	-1,771	0	0	-115	17,482	0	15,595
	27-Jun	-418	0	-418	-1,771	0	0	-115	17,482	0	15,595
	28-Jun	-259	0	-259	-1,100	0	0	-72	10,853	0	9,682
	29-Jun	-231	-31	-263	-982	-31	0	-64	9,688	0	8,611
	30-Jun	0	-72	-72	0	-72	0	0	0	0	-72
	1-Jul	0	-72	-72	0	-72	0	0	0	0	-72
	2-Jul	0	-72	-72	0	-72	0	0	0	0	-72
	3-Jul	0	-72	-72	0	-72	0	0	0	0	-72
	4-Jul	-235	-31	-266	-996	-31	7,900	-65	9,833	0	16,641
	5-Jul	-418	0	-418	-1,771	0	0	-115	17,482	0	15,595
	6-Jul	-411	0	-411	-1,742	0	0	-113	17,190	0	15,335
	7-Jul	0	0	0	0	0	0	0	0	0	0
	8-Jul	0	0	0	0	0	0	0	0	0	0
	9-Jul	-37	-65	-102	-155	-65	0	-10	1,530	0	1,299
	10-Jul	-418	0	-418	-1,771	0	0	-115	17,482	0	15,595
	11-Jul	-418	0	-418	-1,771	0	0	-115	17,482	0	15,595

(continued)

Table 3-6 (continued)

Engine	Date	CASE 1			CASE 2						
		Rod Seal Savings While Idle	Rod Seal Loss Due to Increase While Running	Total Savings	Rod Seal Increase While Idle	Rod Seal Loss Due to Increase While Running	Blowdown Valve Savings	Blowdown Valve Leak Loss	Unit Valve Leak Savings	PRV and Misc. Comp. Loss	Total Savings
	12-Jul	-418	0	-418	-1,771	0	0	-115	17,482	0	15,595
	13-Jul	-270	-25	-295	-1,144	-25	0	-74	11,290	0	10,047
	14-Jul	0	-72	-72	0	-72	0	0	0	0	-72
	15-Jul	-228	-32	-260	-967	-32	7,900	-63	9,542	0	16,380
	16-Jul	-160	-39	-199	-679	-39	0	-44	6,701	0	5,939
	17-Jul	0	-72	-72	0	-72	0	0	0	0	-72
	18-Jul	0	-72	-72	0	-72	0	0	0	0	-72
	19-Jul	0	-72	-72	0	-72	0	0	0	0	-72
	20-Jul	0	-72	-72	0	-72	0	0	0	0	-72
	21-Jul	0	-72	-72	0	-72	0	0	0	0	-72
	22-Jul	-191	-39	-230	-812	-39	7,900	-53	8,012	0	15,009
	23-Jul	-418	0	-418	-1,771	0	0	-115	17,482	0	15,595
	24-Jul	-418	0	-418	-1,771	0	0	-115	17,482	0	15,595
	25-Jul	-418	0	-418	-1,771	0	0	-115	17,482	0	15,595
	26-Jul	-418	0	-418	-1,771	0	0	-115	17,482	0	15,595
	27-Jul	-418	0	-418	-1,771	0	0	-115	17,482	0	15,595
	28-Jul	0	0	0	0	0	0	0	0	0	0
	29-Jul	0	0	0	0	0	0	0	0	0	0
	30-Jul	0	0	0	0	0	0	0	0	0	0
TOTAL		-9,333	-1,069	-10,402	-39,586	-1,069	39,500	-2,575	390,714	0	386,984

Note: Gray areas represent sampling conducted by the Center.

4.0 DATA QUALITY

4.1 BACKGROUND

Information on data quality is used to characterize the level of uncertainty in measured values and verification parameters. The process of establishing data quality objectives starts with determining the desired level of confidence in the primary verification parameters. A primary parameter for Phase I was the establishment of idle-mode gas savings for the France packing. These gas savings are used to help quantify the primary Phase II verification parameter, the France packing payback period. The data quality objective that was established for the payback period defines the quality goals for all measured parameters. It is based on input from gas industry and other Stakeholder Group members, and allows for an error in payback values of about ±3 to 4 months. This goal was used to set data quality goals for the following key measured values: rod packing emissions, valve emissions (unit, blowdown, and pressure relief valves), miscellaneous source emissions, and natural gas quality measurements. This section identifies these goals and discusses how they affect the Phase I verification results.

During the Phase I evaluation, field and laboratory measurements were collected in an effort to quantify uncertainty in the measured values identified above. For example, the accuracy and precision of the flow tube measurement was quantified with frequent calibrations and replicate samples, and these data were used to quantify uncertainty in the packing emissions rates presented in Section 3. These calibrations and replicate samples, along with accuracy and precision data provided by instrument vendors, were used to quantify uncertainty in the key Phase I verification parameter, natural gas savings. As a practical matter, one limitation on the quality and representativeness of the measurements collected is their relative infrequency. Although the level of uncertainty is associated with measurement frequency, it was addressed by repeating all measurements on three separate occasions. On each occasion, measurements were collected at least twice, and each result represented numerous individual quantifications.

4.2 ROD PACKING EMISSION RATE MEASUREMENTS

The MEM Rangemaster flow meters originally planned for use on the doghouse vents did not function properly in the field. As a result, a decision was made to replace these meters with the manual Flow Tube measurements. Based on manufacturer supplied performance data for the MEM meters, the maximum error anticipated was ±2 percent of the instrument's full-scale reading. An error of 5 percent would have allowed the achievement of the data quality objectives set for the payback period and, considering the magnitude of the average emission rates measured at the site, the MEM meter may have resulted in an error of about 6 percent. Calibration data collected on the Flow Tube suggest that the error associated emission rates measured at the site were low, exceeding the original performance goal for the MEM meters.

Table 4-1 presents Phase I calibration results for the Flow Tube, and shows the accuracy values developed from these data. The Flow Tube was calibrated against a laminar flow element (LFE), which itself was calibrated against a NIST-traceable primary standard (r^2 values ranged between 0.9975 and 0.9995). The run-average Flow Tube accuracy values presented were calculated by averaging the accuracy values for each individual measurement in a run. Individual measurement accuracy values were calculated by determining the differences between the Flow Tube and LFE flow rates (flow tube minus LFE), dividing this value by the LFE flow rate, and then multiplying by 100. As the table shows, the

Table 4-1. Flow Tube Calibration Results (Low Flows)

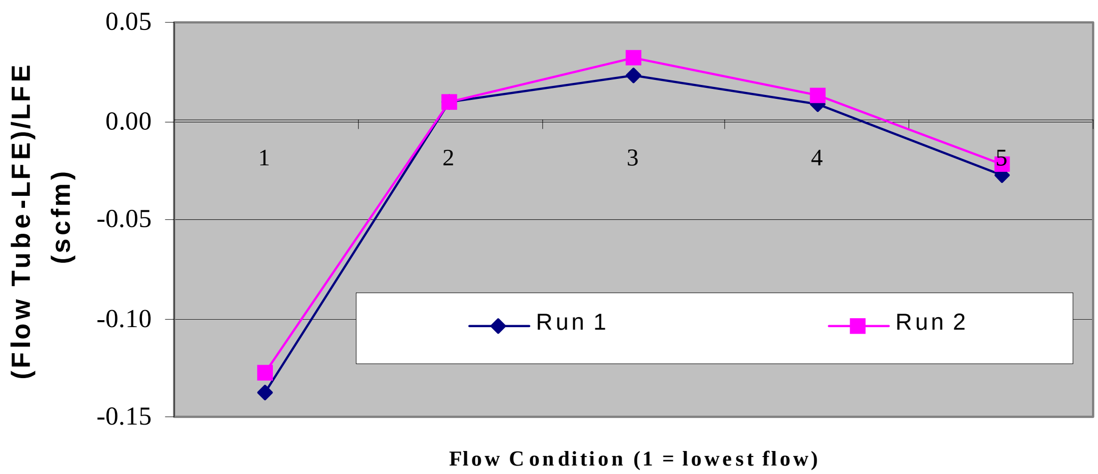
Date	Run	Flow Tube Velocity, fpm	Flow Tube Methane Flow Rate, scfm	LFE Pressure Drop, in. H_2O	LFE Methane Flow Rate, scfm	Flow Tube Accuracy,[a] %
6/2/99	1	102	0.29	0.98	0.34	
		238	0.70	2.00	0.69	
		484	1.44	4.05	1.41	
		711	2.12	6.05	2.10	
		905	2.70	8.00	2.78	
					Run Average	-2.5
6/2/99	2	101	0.30	0.98	0.34	
		236	0.70	2.00	0.69	
		486	1.45	4.05	1.41	
		712	2.13	6.05	2.10	
		908	2.72	8.00	2.78	
					Run Average	-1.9
7/2/99	1	113	0.32	1.02	0.35	
		202	0.70	2.03	0.71	
		368	1.41	4.03	1.40	
		528	2.10	6.02	2.09	
		683	2.77	8.05	2.80	
		843	3.45	10.1	3.52	
					Run Average	-2.3
7/2/99	2	103	0.30	1.04	0.36	
		203	0.72	2.05	0.71	
		370	1.42	3.98	1.38	
		535	2.11	6.01	2.09	
		694	2.78	8.04	2.81	
		850	3.44	10.05	3.51	
					Run Average	-2.7
7/23/99	1	110	0.27	0.92	0.32	
		230	0.72	2.00	0.70	
		427	1.45	4.01	1.41	
		608	2.12	6.01	2.12	
		784	2.77	7.98	2.82	
					Run Average	-2.5
7/23/99	2	107	0.30	1.02	0.36	
		225	0.72	1.99	0.70	
		427	1.45	4.01	1.41	
		612	2.12	5.99	2.12	
		791	2.76	7.96	2.83	
					Run Average	-2.7

[a] Rounding errors may prevent the reader from calculating the exact run average percentages using the concentration data presented in the table.

average accuracy of the Flow Tube ranged from -1.9 to -2.7 percent of the value measured by the LFE (overall average of -2.4 percent). The instrument provided acceptable readings across the flow range represented in Table 4-1, but a relatively consistent negative bias was observed at low flow rates. Specifically, at flows less than about 0.3 scfm, a negative bias (between -11 and -17 percent) was observed for all calibration runs. Fortunately, there were no field measurements collected in this flow regime. In the regime where most measurements were collected (between 0.5 and 3 scfm), the overall average Flow Tube accuracy was 0.4 percent. This value is used to determine the level of actual uncertainty in the net gas savings values described in Section 4.4.

Precision and/or repeatability were assessed by conducting replicate calibrations. The calibrations conducted on 6/2/99 represent the only set of calibration replicates where the reference flow rates (i.e., the LFE flow rates) were precisely duplicated for both runs. In the other calibrations, the duplication of flow conditions was close, but not exact. Figure 4-1 presents a plot of the calibration results collected on 6/2/99. The two lines plot the difference between the Flow Tube flow rates and LFE rates divided by the LFE rates. These values are plotted for each of the five flow rate conditions examined, so if the Flow Tube values were 100 percent repeatable at all flow conditions, only one line would be visible. In this case, repeatability is not exact but is acceptable at all calibration flow conditions. Overall Flow Tube repeatability was calculated for 6/2/99 by: calculating the average difference between the two Flow Tube rates measured for each of two runs at the five flow conditions; dividing this value by the average reference concentration across all flow conditions; and multiplying by 100. This value, calculated to be -0.54 percent, is a measure of the degree of Flow Tube variability observed relative to the actual or reference flow. The trends observed in the 6/2/99 data were apparent in plots of all calibration results collected.

Figure 4-1. Flow Tube Repeatability (6/2/99)



Gas savings for the rod packing are determined as the difference between the packing emission rates measured on the Test and Control Rods. Thus, the total error in the difference is the sum of the absolute errors in each measurement. This principle, along with the average accuracy value of 0.4 percent described earlier, is used to determine potential levels of error in net gas savings values presented in Section 3. This overall error is presented in Section 4.4.

Finally, the original completeness goal for rod packing emissions measurements required the completion of 15 sets of measurements. As discussed in Section 3, 14 complete sets of measurements were collected.

4.3 OTHER MEASUREMENTS

4.3.1 Unit Valve, Blowdown Valve, and Pressure Relief Valve

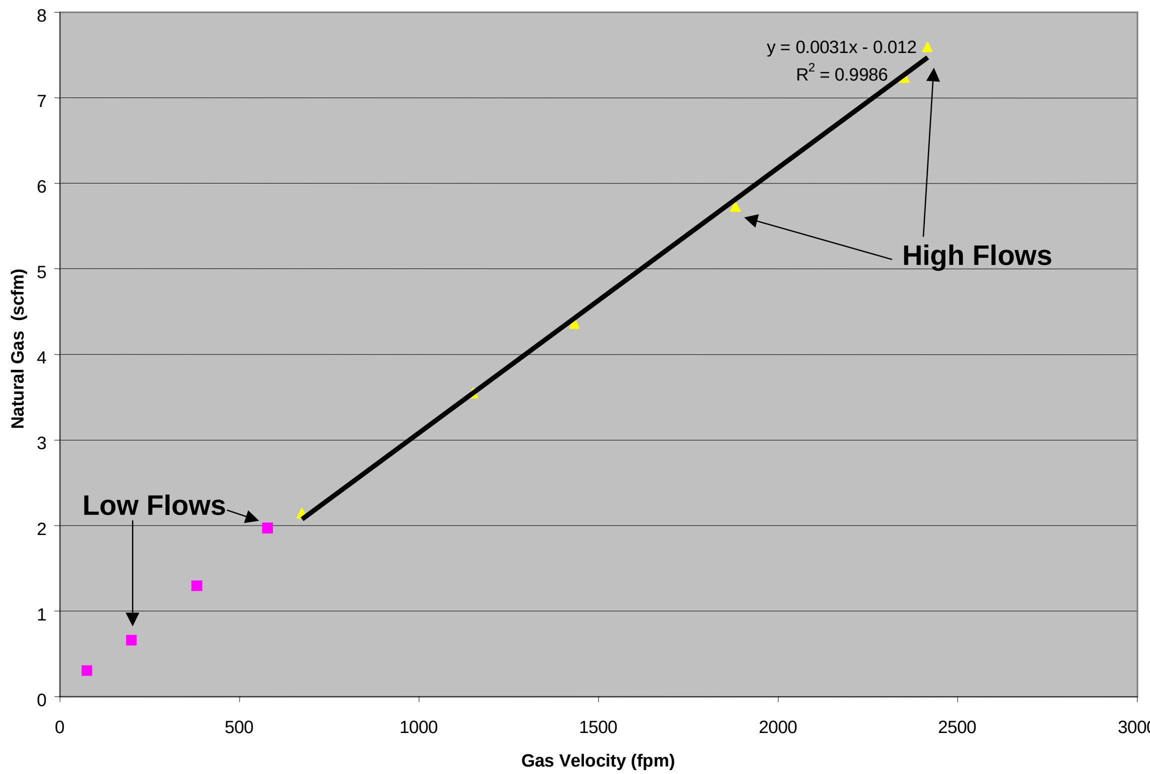
Measurement of the leak rates for the blowdown valve, pressure relief valve, and unit valves were made using different calibrated instruments. QA results associated with each of these measurements are described below. Data quality considerations for the estimated blowdown volume are also discussed.

The pressure relief and unit valves were measured using the Flow Tube discussed earlier. Because flow was not detected for any pressure relief valves, QA and calibration data are not presented for them. For the unit valve, the Flow Tube calibration data presented in Section 4.2 are applicable to the few low flow rate measurements collected on this device. In most cases, flow rates were higher, and a high flow calibration chart was developed and used after the field study was completed to convert measured gas velocities into natural gas flow rates. The same Flow Tube calibration procedure described for the rod packing vent measurements was followed here, and the calibration data developed are presented in Table 4-2 (Note: it was not feasible to simulate gas flows greater than 8 scfm in the laboratory). A calibration chart, similar to the Flow Tube calibration chart presented in Section 2 for the rod packing vent measurements, is shown in Figure 4-2. The Flow Tube accuracy at high flow rate regimes was found to perform as good as or better than the accuracy observed at lower flow regimes. Figure 4-2 clearly shows that the natural gas flow rate is linearly proportional to the gas velocity measured with the Flow Tube (at both high and low flow rate regimes). For this reason, the equation shown in the figure was used to extrapolate the calibration data, and estimate gas flow rates at higher velocity readings. The accuracy and precision of the Flow Tube in high flow rate regimes approximated those at lower flow rate regimes.

Table 4-2. Flow Tube Calibration Results (High Flows)

Date	Run	Flow Tube Velocity, fpm	Flow Tube Methane Flow Rate, scfm	LFE Pressure Drop, in. H_2O	LFE Methane Flow Rate, scfm	Flow Tube Accuracy, %
8/11/99	1	674	2.08	0.25	2.14	
		1150	3.55	0.41	3.55	
		1433	4.43	0.50	4.36	
		1881	5.82	0.65	5.72	
		2351	7.28	0.81	7.23	
		2416	7.48	0.85	7.39	
					Run Average	-0.1
8/11/99	2	179	0.06	0.07	0.60	
		725	2.19	0.25	2.15	
		1207	3.58	0.41	3.54	
		1458	4.31	0.50	4.34	
		1928	5.67	0.65	5.70	
		2286	6.71	0.75	6.61	
					Run Average	0.7

Figure 4-2. Flow Tube Calibration at High Flows (8/11/99)



The Flow Tube was originally planned for use on the blowdown valve as well. However, early field results suggested that the flow rates from the blowdown valve were very low, and Flow Tube calibrations suggested that performance was poor in this regime (i.e., there is no response). Therefore, a low flow rate rotameter was used to conduct measurements on the blowdown valve. The calibration results for this device are presented in Table 4-3. The original accuracy goals for this measured parameter are also shown for comparison.

Table 4-3. Rotameter Calibration Results

Measurement Instrument Used	Calibration Date	Range	Accuracy		Precision	
			Goal	Actual	Goal	Actual
Rotameter (Dwyer VB Series)	8/9	0 to 1000 mL/min	3	1.38	3	-0.73

For the miscellaneous components such as flanges and valve stems, it was not possible to effectively channel the leaking gas to the flow tube. For these types of fugitive sources, soap-screening was used to identify significant leaks, and when flow rate determination was needed, EPA's protocol tent/bag method was planned for use. Because significant leaks were not found, the tent/bag method was not applied. The data quality information for this method is not presented.

The average accuracy values presented here are used later in Section 4.4 to assess how these measured values may contribute to overall uncertainty in the natural gas savings estimated for Case 1 and Case 2.

4.3.2 Gas Composition

Based on average gas compositional data supplied by ANR, the average methane concentration in the natural gas was determined to be 97.09 percent. The accuracy of these readings was determined to be 0.12 percent

4.3.3 Blowdown Volume

Blowdown volume was quantified based on the volume of piping and manifolds in the compressor system, and is accurate to within the piping specifications (assumed to be 100 percent accurate). The unit pressure, which was measured at the station by ANR engine monitors, was used to convert the calculated volume into a volume of natural gas at standard conditions. Generally, the host site operated at about 600 psig suction pressure. Unfortunately, calibration records for the pressure monitor were not made available by ANR, so accuracy estimates for this measured parameter could not be determined. However, the accuracy of the pressure sensor was not required because blowdown volume was calculated based on a typical suction pressure of 600 psig.

4.4 OVERALL UNCERTIANTY IN THE MEASUREMENTS, NET GAS SAVINGS, AND METHANE EMISSIONS VALUES

Calibrations were conducted by the Center on most of the instruments used in this verification. These data are summarized in Table 4-4. In a few cases, performance data supplied by either the instrument vendor or ANR Pipeline were used. These data are also presented in Table 4-4.

Table 4-4. Summary of Instrument Performance Data

Measurement Instrument Used	Applicable Source	Source of Performance Data	Accuracy (%)	Precision (%)
Flow Tube	Doghouse Vents	The Center	-2.4 (0.4)[a]	-0.54
	Pressure Relief Valve Leaks	The Center	-2.4	-0.54
	Unit Valve Leaks	The Center	+ 0.31	+ 1.37
Rotameter	Blowdown Valve Leaks	The Center	+ 1.38	- 0.73
Gas Chromatograph	All (convert natural gas emissions into methane emissions)	ANR Pipeline	0.12	not available
Hydrocarbon Analyzer	Pressure Relief Valve Misc. Components	The Center	1.5	0.5

[a] The value in parentheses represents the accuracy at flow regimes encountered in the field. It was used to assess uncertainty in net gas savings values as described below.

The measurement accuracy values presented above were used to calculate how measurement error might propagate through the calculation process used to determine net gas savings and methane emissions for the France packing. Based on these calculations, uncertainty or potential error in the net gas savings and methane emissions values due to instrumentation is estimated to be ±5 percent for Case 1. For Case 2, more individual measurements were collected, and a greater opportunity for error existed. In this case, the overall uncertainty or potential error due to measurements instruments is estimated to be ±8 percent.

It should be noted that the estimated errors above represent uncertainty introduced by the measurements methods used. They do not include uncertainty or bias that could be introduced into the results attributable to: differences in the host sites design or operating characteristics relative to other sites; the frequency of measurements conducted; and environmental, diurnal, geographic, or other potential biasing factors. The Center conducted this evaluation over a 4-week period, and collected several separate measurements data sets, in an effort to address some of these potentially biasing factors. Based on the Student's t distribution analysis shown earlier in Section 3, it is clear that process variability is introducing errors that are greater than the instrument errors. The Center is investigating more sensitive instruments that may be able to detect some of this variability. It is expected that some level of process variability may still exist and may not be addressed with the measurement scheme used in this verification.

5.0 REFERENCES

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